**AP Bio/IB Bio Concordance**

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|  | AP Essential Knowledge | | | | IB Assessment Statement |
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| **1.A.1 Natural selection is a major mechanism of evolution** | | | | | |
| 1.A.1a | According to Darwin’s theory of natural selection, competition for limited resources results in differential survival. Individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations. | | | | 5.4.3 State that populations tend to produce more offspring than the environment can support.  5.4.4 Explain that the consequences of the potential overproduction of offspring is a struggle for survival  5.4.7 Explain how natural selection leads to evolution *IB says: Greater survival and reproductive success of individuals with favorable heritable variations can lead to change in the characteristics of a population.* |
| 1.A.1b | Evolutionary fitness is measured by reproductive success | | | |  |
| 1.A.1c | Genetic variation and mutation play roles in natural selection. A diverse gene spool is important for the survival of a species in a changing environment. | | | | 5.4.5 State that the members of a species show variation  5.4.6 Explain how sexual reproduction promotes variation in a species |
| 1.A.1d | Environments can be more or less stable or fluctuating, and this affects evolutionary rate and direction; different genetic variations can be selected in each generation. | | | |  |
| 1.A.1e | An adaptation is a genetic variation that is favored by selection and is manifested as a trait that provides an advantage to an organism in a particular environment. | | | | E.6.5 Explain how mate selection can lead to exaggerated traits |
| 1.A.1f | In addition to natural selection, chance and random events can influence the evolutionary process, especially for small populations | | | |  |
| 1.A.1g | Conditions for a population or an allele to be in Hardy-Weinberg equilibrium are: (1) a large population size, (2) absence of migration, (3) no net mutations, (4) random mating, and (5) absence of selection. These conditions are seldom met. | | | | D.4.1 Explain how the Hardy-Weinberg equation is derived.  D.4.2 Calculate allele, genotype, and phenotype frequencies for two alleles of a gene, using the Hardy-Weinberg equation.  D.4.3 State the assumptions made when the Hardy-Weinberg equation is used. |
| 1.A.1h | Mathematical approaches are used to calculate changes in allele frequency, providing evidence for the occurrence of evolution in a population. (*Illustrative examples: Graphical analysis of allele frequencies in a population; application of the Hardy-Weinberg equilibrium equation).* | | | | D.2.1 Define *allele frequency* and *gene pool*  D.2.2 State that evolution involves a change in allele frequency in a population’s gene pool over a number of generations. |
| LO1.1 | The student is able to convert a data set from a table of numbers that reflect a change in genetic makeup of a population over time and to apply mathematical methods and conceptual understandings to investigate the cause(s) and effect(s) of this change. | | | |  |
| LO1.2 | The student is able to evaluate evidence provided by data to qualitatively and quantitatively investigate the role of natural selection in evolution. | | | |  |
| LO1.3 | The student is able to apply mathematical methods to data from a real or simulated population to predict what will happen to the population in the future. | | | |  |
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| **1.A.2 Natural selection acts on phenotypic variations in populations** | | | | | |
| 1.A.2a | Environments change and act as selective mechanisms on populations. (*Illustrative examples: flowering time in relation to global climate change; peppered moth)* | | | |  |
| 1.A.2b | Phenotypic variations are not directed by the environment but occur through random changes in the DNA and through new gene combinations | | | |  |
| 1.A.2c | Some phenotypic variations significantly increase or decrease fitness of the organism and the population *(Illustrative examples: Sickle cell anemia, peppered moth, DDT resistance in insects)* | | | |  |
| 1.A.2d | Humans impact variation in other species (*illustrative examples: artificial selection, loss of genetic diversity within a crop species, overuse of antibiotics)* | | | |  |
| LO1.4 | The student is able to evaluate data-based evidence that describes evolutionary changes in the genetic makeup of a population over time | | | |  |
| LO1.5 | The student is able to connect evolutionary changes in a population over time to a change in the environment | | | | 5.4.8 Explain two examples of evolution in response to environmental change; one must be antibiotic resistance in bacteria. |
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| **1.A.3 Evolutionary change is also driven by random processes** | | | | | |
| 1.A.3a | Genetic drift is a nonselective process occurring in small populations | | | |  |
| 1.A.3b | Reduction in genetic variation within a given population can increase the differences between populations of the same species | | | |  |
| LO1.6 | The student is able to use data from mathematical models based on the Hardy-Weinberg equilibrium to analyze genetic drift and effects of selection in the evolution of specific populations. | | | | D.4 |
| LO1.7 | The student is able to justify data from mathematical models based on the Hardy-Weinberg equilibrium to analyze genetic drift and the effects of selection in the evolution of specific populations. | | | |  |
| LO1.8 | The student is able to make predictions about the effects of genetic drift, migration, and artificial selection on the genetic makeup of a population. | | | |  |
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| **1.A.4 Biological evolution is supported by scientific evidence from many disciplines, including mathematics** | | | | | |
| 1.A.4a | Scientific evidence of biological evolution uses information from geographical, geological, physical, chemical and mathematical applications. | | 5.4.1 Define *evolution IB says: Evolution is the cumulative change in the heritable characteristics of a population.*  5.4.2 Outline the evidence for evolution provided by the fossil record, selective breeding of domesticated animals, and homologous structures | | |
| 1.A.4b | Molecular, morphological, and genetic information of existing and extinct organisms add to our understanding of evolution. | |  | | |
| 1.A.4b1 | Fossils can be dated by a variety of methods that provide evidence for evolution. These include the age of rocks where a fossil is found, the rate of decay of isotopes including carbon-14, the relationships within phylogenetic trees, and the mathematical calculations that take into account information from chemical properties and/or geographical data. *(Exclusion: The details of these methods are beyond the scope of this course.)* | | D.3.1 Outline the method for dating rocks and fossils using radioisotopes, with reference to 14C and 40K.  D.3.2 Define *half-life*  D.3.3 Deduce the approximate age of materials based on a simple decay curve for a radioisotope.  D.3.7 Discuss the incompleteness of the fossil record and the resulting uncertainties about human evolution. | | |
| 1.A.4b2 | Morphological homologies represent features shared by common ancestry. Vestigial structures are remnants of functional structures, which can be compared to fossils and provide evidence for evolution. | | D.5.6 Distinguish, with examples, between *analogous* and *homologous* characteristics. | | |
| 1.A.4b3 | Biochemical and genetic similarities, in particular DNA nucleotide and protein sequences, provide evidence for evolution and ancestry. | | D.5.2 Explain the biochemical evidence provided by the universality of DNA and protein structures for the common ancestry of living organisms.  D.5.3 Explain how variations in specific molecules can indicate phylogeny.  D.5.4 Discuss how biochemical variations can be used as an evolutionary clock. | | |
| 1.A.4b4 | Mathematical models and simulations can be used to illustrate and support evolutionary concepts. (*Illustrative examples: Graphical analyses of allele frequencies in a population; analysis of sequence data sets; analysis of phylogenetic trees; construction of phylogenetic trees based on sequence data.)* | |  | | |
| LO1.9 | The student is able to evaluate evidence provided by data from many scientific disciplines that support biological evolution. | |  | | |
| LO1.10 | The student is able to refine evidence based on data from many scientific disciplines that support biological evolution. | |  | | |
| LO1.11 | The student is able to design a plan to answer scientific questions regarding how organisms have changed over time using information from morphology, biochemistry and geology. | |  | | |
| LO1.12 | The student is able to connect scientific evidence from many scientific disciplines to support the modern concept of evolution. | |  | | |
| LO1.13 | The student is able to construct and/or justify mathematical models, diagrams, or simulations that represent processes of biological evolution. | |  | | |
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| **1.B.1 Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today** | | | | | |
| 1.B.1a | Structural and functional evidence supports the relatedness of all domains | |  | | |
| I.B.1a1 | DNA and RNA are carriers of genetic information through transcription, translation, and replication | |  | | |
| 1.B.1a2 | Major features of the genetic code are shared by all modern living systems | | 4.4.7 State that, when genes are transferred between species, the amino acid sequence of polypeptides translated from them is unchanged because the genetic code is universal. | | |
| 1.B.1a3 | Metabolic pathways are conserved across all currently recognized domains. | |  | | |
| 1B.1b | Structural evidence supports the relatedness of all eukaryotes (*Illustrative example: Cytoskeleton, membrane-bound organelles, linear chromosomes, endomembrane systems)* | |  | | |
| LO1.14 | The student is able to pose scientific questions that correctly identify essential properties of shared, core life processes that provide insights into the history of life on Earth. | |  | | |
| LO1.15 | The student is able to describe specific examples of conserved core biological processes and features shared by all domains or within one domain of life, and how these shared, conserved core processes and features support the concept of common ancestry for all organisms. | |  | | |
| LO1.16 | The student is able to justify the scientific claim that organisms share many conserved core processes and features that evolved and are widely distributed among organisms today. | |  | | |
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| **1.B.2 Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested.** | | | | | |
| 1.B.2a | Phylogenetic trees and cladograms can represent traits that are either derived or lost due to evolution *(Illustrative examples: number of heart chambers in animals; opposable thumbs; absence of legs in some sea mammals)* | | D.5.5 Define *clade* and *cladistics*  D.5.7 Outline the methods used to construct cladograms and the conclusions that can be drawn from them.  D.5.8 Construct a simple cladogram.  D.5.9 Analyse cladograms in terms of phylogenetic relationships.  D.5.10 Discuss the relationship between cladograms and the classification of living organisms. | | |
| 1.B.2b | Phylogenetic trees and cladograms illustrate speciation that has occurred, in that relatedness of any two groups on the tree is shown by how recently two groups had a common ancestor | |  | | |
| 1.B.2c | Phylogenetic trees and cladograms can be constructed from morphological similarities of living or fossil species, and from DNA and protein sequence similarities, by employing computer programs that have sophisticated ways of measuring and representing relatedness among organisms | |  | | |
| 1.B.2d | Phylogenetic trees and cladograms are dynamic (i.e. phylogenetic trees and cladograms are constantly being revised), based on the biological data used, new mathematical and computational ideas, and current and emerging knowledge | |  | | |
| LO1.17 | The student is able to pose scientific questions about a group of organisms whose relatedness is described by a phylogenetic tree or cladogram in order to (1) identify shared characteristics, (2) make inferences about the evolutionary history of the group, and (3) identify character data that could extend or improve the phylogenetic tree | |  | | |
| LO1.18 | The student is able to evaluate evidence provided by a data set in conjunction with a phylogenetic tree or a simple cladogram to determine evolutionary history and speciation | |  | | |
| LO1.19 | The student is able to create a phylogenetic tree or simple cladogram that correctly represents evolutionary history and speciation from a provided data set. | |  | | |
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| **1.C.1 Speciation and extinction have occurred throughout Earth’s history** | | | | | |
| 1.C.1a | Speciation rates can vary, especially when adaptive radiation occurs when new habitats become available | | D.2.7 Outline the process of adaptive radiation | | |
| 1.C.1b | Species extinction rates are rapid at times of ecological stress (*Illustrative examples: Five major extinctions; human impact on ecosystems and species extinction rates) (Exclusion: The names and dates of these extinctions)* | |  | | |
| LO1.20 | The student is able to analyze data related to questions of speciation and extinction throughout Earth’s history | |  | | |
| LO1.21 | The student is able to design a plan for collecting data to investigate the scientific claim that speciation and extinction have occurred throughout the Earth’s history | |  | | |
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| **Speciation may occur when two populations become reproductively isolated from each other** | | | | | |
| 1.C.2a | Speciation results in diversity of life forms. Species can be physically separated by a geographic barrier such as an ocean or a mountain range, or various pre- and post-zygotic mechanisms can maintain reproductive isolation and prevent gene flow. | | D.2.3 Discuss the definition of the term species.  D.2.4 Describe three examples of barriers between gene pools.  D.2.6 Compare allopatric and sympatric speciation. | | |
| 1.C.2b | New species arise from reproductive isolation over time, which can involve scales of hundreds of thousands or even millions of years, or speciation can occur rapidly through mechanisms such as polyploidy in plants. | | D.2.5 Explain how polyploidy can contribute to speciation | | |
| LO1.22 | The student is able to use data from a real or simulated population(s), based on graphs or models of types of selection, to predict what will happen to the population in the future. | |  | | |
| LO1.23 | The student is able to justify the selection of data that address questions related to reproductive isolation and speciation. | |  | | |
| LO1.24 | The student is able to describe speciation in an isolated population and connect it to change in gene frequency, change in environment, natural selection and/or genetic drift. | |  | | |
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| **1.C.3 Populations of organisms continue to evolve** | | | | | |
| 1.C.3a | Scientific evidence supports the idea that evolution has occurred in all species | | | |  |
| 1.C.3b | Scientific evidence supports the idea that evolution continues to occur (*illustrative examples: chemical resistance, emergent diseases, observed directional phenotypic change in a population e.g. Grants' observations of Darwin's finches; a eukaryotic example that describes evolution of a structure or process such as heart chambers, limbs, the brain and the immune system)* | | | | 5.4.8 |
| LO1.25 | The student is able to describe a model that represents evolution within a population | | | |  |
| LO1.26 | The student is able to evaluate given data sets that illustrate evolution as an ongoing process | | | |  |
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| **1.D.1 There are several hypotheses about the natural origin of life on Earth, each with supporting scientific evidence** | | | | | |
| 1.D.1a | Scientific evidence supports the various models | | | | D.1.2 Outline the experiments of Miller and Urey into the origin of organic compounds.  D.1.3 State that comets may have delivered organic compounds to Earth. |
| 1.D.1a1 | Primitive Earth provided inorganic precursors from which organic molecules could have been synthesized due to the presence of available free energy and the absence of a significant quantity of oxygen | | | | D.1.1 Describe four processes needed for the spontaneous origin of life on Earth. |
| 1.D.1a2 | In turn, these molecules served as monomers or building blocks for the formation of more complex molecules, including amino acids and nucleotides. | | | |  |
| 1.D.1a3 | The joining of these monomers produced polymers with the ability to replicate, store, and transfer information. | | | |  |
| 1.D.1a4 | These complex reaction sets could have occurred in solution (organic soup model) or as reactions on solid reactive surfaces. | | | | D.1.4 Discuss possible locations where conditions would have allowed the synthesis of organic compounds. |
| 1.D.1a5 | The RNA World hypothesis proposes that RNA could have been the earliest genetic material | | | | D.1.5 Outline two properties of RNA that would have allowed it to play a role in the origin of life. |
| LO1.27 | The student is able to describe a scientific hypothesis about the origin of life on Earth | | | |  |
| LO1.28 | The student is able to evaluate scientific questions based on hypotheses about the origin of life on Earth. | | | |  |
| LO1.29 | The student is able to describe the reasons for revisions of scientific hypotheses of the origin of life on Earth. | | | |  |
| LO1.30 | The student is able to evaluate scientific hypotheses about the origin of life on Earth. | | | |  |
| LO1.31 | The student is able to evaluate the accuracy and legitimacy of data to answer scientific questions about the origin of life on Earth. | | | |  |
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| **1.D.2 Scientific evidence from many different disciplines supports models of the origin of life** | | | | | |
| 1.D.2a | Geological evidence provides support for models of the origin of life on Earth | | | |  |
| 1.D.2a1 | The Earth formed approximately 4.6 billion years ago, and the environment was too hostile for life until 3.9 bya, while the earliest fossil evidence for life dates to 3.5 bya. Taken together, this evidence provides a plausible range of dates when the origin of life could have occurred. | | | |  |
| 1.D.2a2 | Chemical experiments have shown that it is possible to form complex organic molecules from inorganic molecules in the absence of life. | | | |  |
| 1.D.2b | Molecular and genetic evidence from extant and extinct organisms indicate that all organisms share a common ancestral origin of life | | | |  |
| 1.D.2b1 | Scientific evidence includes molecular building blocks that are common to all life forms | | | |  |
| 1.D.2b2 | Scientific evidence includes a common genetic code | | | |  |
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| **2.A.1 All living systems require constant input of free energy** | | | | | |
| 2.A.1a | Life requires a highly ordered system | |  | | |
| 2.A.1a1 | Order is maintained by constant free energy input into the system | |  | | |
| 2.A.1a2 | Loss of order or free energy flow results in death | |  | | |
| 2.A.1a3 | Increased disorder and entropy are offset by biological processes that maintain or increase order | |  | | |
| 2.A.1b | Living systems do not violate the second law of thermodynamics, which states that entropy increases over time. | |  | | |
| 2.A.1b1 | Order is maintained by coupling cellular processes that increase entropy (and so have negative changes in free energy) with those that decrease entropy (and so have positive changes in free energy) | |  | | |
| 2.A.1b2 | Energy input must exceed free energy lost to entropy to maintain order and power cellular processes | |  | | |
| 2.A.1b3 | Energetically favorable exergonic reactions, such as ATP-->ADP that have a negative change in free energy can be used to maintain or increase order in a system by being coupled with reactions that have a positive free energy change. | |  | | |
| 2.A.1c | Energy-related pathways in biological systems are sequential and may be entered at multiple points in the pathway (*illustrative examples: Krebs cycle, glycolysis, Calvin cycle, fermentation)* | | 7.6.1 State that metabolic pathways consist of chains and cycles of enzyme-catalysed reactions. | | |
| 2.A.1d | Organisms use free energy to maintain organization, grow, and reproduce | |  | | |
| 2.A.1d1 | Organisms use various strategies to regulate body temperature and metabolism (*Illustrative examples: Endothermy, ectothermy, elevated floral temperatures in some plant species)* | |  | | |
| 2.A.1d2 | Reproduction and rearing of offspring require free energy beyond that used for maintenance and growth. Different organisms use various reproductive strategies in response to energy available. (*Illustrative examples: seasonal reproduction in animals and plants; life-history strategy, e.g. biennial plants, reproductive diapause)* | |  | | |
| 2.A.1d3 | There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms--generally, the smaller the organism, the higher the metabolic rate | |  | | |
| 2.A.1d4 | Excess acquired free energy versus required free energy expenditure results in energy storage or growth | |  | | |
| 2.A.1d5 | Insufficient acquired free energy versus required free energy expenditure results in loss of mass and, ultimately, the death of an organism | |  | | |
| 2.A.1e | Changes in free energy availability can result in changes in population size | | 5.3.1 Outline how population size is affected by natality, immigration, mortality, and emigration  5.3.2 Draw and label a graph showing the sigmoid (S-shaped) population growth curve  5.3.3 Explain the reasons for the exponential growth phase, the plateau phase, and transitional phase between these two phases  5.3.4 List three factors that set limits to population increase | | |
| 2.A.1f | Changes in free energy availability can result in disruptions to an ecosystem (*illustrative examples: change in the producer level can affect the number and size of other trophic levels; change in energy resources levels such as sunlight can affect the number and size of trophic levels)* | | 5.1.6 Define *trophic level*  5.1.7 Deduce the trophic level of organisms in a food chain or food web  5.1.9 State that light is the initial energy source for almost all communities  5.1.10 Explain the energy flow in a food chain.  5.1.11 State that energy transformation are never 100% efficient.  5.1.12 Explain reasons for the shape of the pyramids of energy. | | |
| LO2.1 | The student is able to explain how biological systems use free energy based on empirical data that all organisms require constant energy input to maintain organization, to grow and to reproduce | | 3.2.7 Compare the use of carbohydrates and lipids in energy storage **Maybe?** | | |
| LO2.2 | The student is able to justify a scientific claim that free energy is required for living systems to maintain organization, to grow or to reproduce, but that multiple strategies exist in different living systems | |  | | |
| LO2.3 | The student is able to predict how changes in free energy availability affect organisms, populations and ecosystems | |  | | |
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| **2.A.2 Organisms capture and store free energy for use in biological processes** | | | | | |
| 2.A.2a | Autotrophs capture free energy from physical sources in the environment | | 5.1.2 Distinguish between *autotroph* and *heterotroph. Autotroph—an organism that synthesizes its organic molecules from simple inorganic substances* | | |
| 2.A.2a1 | Photosynthetic organisms capture free energy present in sunlight | |  | | |
| 2.A.2a2 | Chemosynthetic organisms capture free energy from small inorganic molecules present in their environment, and this process can occur in the absence of oxygen | |  | | |
| 2.A.2b | Heterotrophs capture free energy present in carbon compounds produced by other organisms | | 5.1.2 Distinguish between *autotroph* and *heterotroph*  *Heterotroph—an organism that obtains organic molecules from other organisms* | | |
| 2.A.2b1 | Heterotrophs may metabolize carbohydrates, lipids, and proteins by hydrolysis as sources of free energy | |  | | |
| 2.A.2b2 | Fermentation produces organic molecules, including alcohol and lactic acid, and it occurs in the absence of oxygen (*Exclusion: specific steps, names of enzymes, and intermediates of the pathways for these processes)* | | 3.7.3 Explain that, during anaerobic respiration, pyruvate can be converted in the cytoplasm into lactate, or ethanol and carbon dioxide, with no further yield of ATP. | | |
| 2.A.2c | Different energy-capturing processes use different types of electron acceptors (*example: NADP+ in photosynthesis, oxygen in cellular respiration)* | |  | | |
| 2.A.2d | The light-dependent reactions of photosynthesis in eukaryotes involve a series of coordinated reaction pathways that capture free energy present in light to yield ATP and NADPH, which power the production of organic molecules | | 3.8.1 State that photosynthesis involves the conversion of light energy into chemical energy.  3.8.6 State that light energy is used to produce ATP, and to split water molecules (photolysis) to form oxygen and hydrogen.  8.2.2 State that photosynthesis consists of light-dependent reactions and light-independent reactions  8.2.3 Explain the light-dependent reactions. IB says: *Include the photoactivation of photosystem II, photolysis of water, electron transport, cyclic and non-cyclic phosphorylation, photoactivation of photosystem I, and reduction of NADP+.* | | |
| 2.A.2d1 | During photosynthesis, chlorophylls absorb free energy from light, boosting electrons to a higher energy level in Photosystems I and II | | 3.8.3 State that chlorophyll is the main photosynthetic pigment.  3.8.4 Outline the differences in absorption of red, blue, and green light by chlorophyll. IB says: *Students should appreciate that pigments absorb certain colors of light. The remaining colors of light are reflected. It is not necessary to mention wavelengths or the structure responsible for the absorption.*  8.2.3 | | |
| 2.A.2d2 | Photosystems I and II are embedded the internal membrane of chloroplasts (thylakoids) and are connected by the transfer of higher free energy electrons through an electron transport chain (ETC) | | 8.2.3 | | |
| 2.A.2d3 | When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of hydrogen ions (protons) across the thylakoid membrane is established | | 8.2.4 Explain photophosphorylation in terms of chemiosmosis  *IB says: Include the roles of ribulose bisphosphate (RuBP), carboxylase, reduction of glycerate 3-phosphate (GP) to triose phosphate (TP), NADPH + H+, ATP, regeneration of RuBP, and subsequent synthesis of more complex carbohydrates.* | | |
| 2.A.2d4 | The formation of the proton gradient is a separate process, but it is linked to the synthesis of ATP from ADP and inorganic phosphate via ATP synthase | | 8.2.4 | | |
| 2.A.2d5 | The energy captured in the light reactions as ATP and NADPH powers the production of carbohydrates from carbon dioxide in the Calvin cycle, which occurs in the stroma of the chloroplast | | 8.2.5 Explain the light-independent reactions IB says: *Include the role of ribulose bisphosphate (RuBP) carboxylase, reduction of glycerate-3-phosphate (GP) to triose phosphate (TP), NADPH +H+, ATP, regeneration of RuBP, and subsequent synthesis of more complex carbohydrates.* | | |
|  | *Exclusion: memorization of the steps in the Calvin cycle, the structure of the molecules and the names of the enzymes, with the exception of ATP synthase* | |  | | |
| 2.A.2e | Photosynthesis first evolved in prokaryotic organisms; scietnific evidence supports that prokaryotic (bacterial) photosynthesis was responsible for the production of an oxygenated atmosphere; prokaryotic photosynthetic pathways were the foundation of eukaryotic photosynthesis | | D.1.7 Outline the contribution of prokaryotes to the creation of an oxygen-rich atmosphere. | | |
| 2.A.2f | Cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that harvest free energy from simple carbohydrates | | 3.7.1 Define *cell respiration*. *IB says: Cell respiration is the controlled release of energy from organic compounds in cells to form ATP.* | | |
| 2.A.2f1 | Glycolysis rearranges the bonds in glucose molecules, releasing free energy to form ATP from ADP and inorganic phosphate, and resulting in the production of pyruvate | | 3.7.2 State that, in cell respiration, glucose in the cytoplasm is broken down by glycolysis into pyruvate, with a small yield of ATP.  8.1.2 Outline the process of glycolysis, including phosphorylation, lysis, oxidation, and ATP formation | | |
| 2.A.2f2 | Pyruvate is transported from the cytoplasm to the mitochondrion, where further oxidation occurs | | 3.7.4 Explain that, during aerobic cell respiration, pyruvate can be broken down in the mitochondria into carbon dioxide and water with a large yield of ATP. | | |
| 2.A.2f3 | In the Krebs cycle, carbon dioxide is released from organic intermediates. ATP is synthesized from ADP and inorganic phosphate via substrate level phosphorylation and electrons are captured by coenzymes. | | 8.1.4 Explain aerobic respiration, including the link reaction, the Krebs cycle, the role of NADH + H+, the electron transport chain, and the role of oxygen | | |
| 2.A.2f4 | Electrons that are extracted in the series of Krebs cycle reactions are carried by NADH and FADH2 to the electron transport chain. | | 8.1.4 | | |
|  | *Exclusion: memorization of the steps in glycolysis and the Krebs cycle, or of the structures of the molecules and the names of the enzymes invoved.* | |  | | |
| 2.A.2g | The electron transport chain captures free energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes | | 8.1.4 | | |
| 2.A.2g1 | Electron transport chain reactions occur in chloroplasts (photosynthesis), mitochondria (cellular respiration), and prokaryotic plasma membranes | |  | | |
| 2.A.2g2 | In cellular respiration, electrons delivered by NADH and FADH2 are passed to a series of electron acceptors as they move toward the terminal electron acceptor, oxygen. In photosynthesis, the terminal electron acceptor is NADP+. | | 8.1.4 | | |
| 2.A.2g3 | The passage of electrons is accompanied by the formation of a proton gradient across the inner mitochondrial membrane or the thylakoid membrane of chloroplasts, with the membrane(s) separating a region of high proton concentration from a region of low proton concentration. In prokaryotes, the passage of electrons is accompanied by the outward movement of protons across the plasma membrane. | | 8.1.5 Explain oxidative phosphorylation in terms of chemiosmosis | | |
| 2.A.2g4 | The flow of protons back through membrane-bound ATP synthase by chemiosmosis generates ATP from ADP and inorganic phosphate. | | 8.1.5 | | |
| 2.A.2g5 | In cellular respiration, decoupling oxidative phosphorylation from electron transport is involved in thermoregulation | | 8.1.5 | | |
|  | *Exclusion: The names of the specific electron carriers in the ETC* | |  | | |
| 2.A.2h | Free energy becomes available for metabolism by the conversion of ATP-->ADP, which is coupled to many steps in metabolic pathways | |  | | |
| LO2.4 | The student is able to use representations to pose scientific questions about what mechanisms and structural features allow organisms to capture, store and use free energy | |  | | |
| LO2.5 | The student is able to construct explanations of the mechanisms and structural features of cells that allow organisms to capture, store or use free energy | |  | | |
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| **2.A.3 Organisms must exchange matter with the environment to grow, reproduce, and maintain organization** | | | | | |
| 2.A.3a | Molecules and atoms from the environment are necessary to build new molecules | |  | | |
| 2.A.3a1 | Carbon moves from the environment to organisms where it is used to build carbohydrates, proteins, lipids, or nucleic acids. Carbon is used in storage compounds and cell formation in all organisms. | | 3.1.1 State that the most frequently occurring chemical elements in living things are hydrogen, oxygen, carbon, and nitrogen | | |
| 2.A.3a2 | Nitrogen moves from the environment to organisms where it is used in building proteins and nucleic acids. Phosphorus moves from the environment to organisms where it is used in nucleic acids and certain lipids. | | 3.1.1 State that the most frequently occurring chemical elements in living things are hydrogen, oxygen, carbon, and nitrogen | | |
| 2.A.3a3 | Living systems depend on properties of water that result from its polarity and hydrogen bonding. (*Examples: Cohesion, adhesion, high specific heat capacity, universal solvent supports reactions, heat of vaporization, heat of fusion, water's thermal conductivity)* | | 3.1.4 Draw and label a diagram showing the structure of water molecules to show their polarity and hydrogen bond formation  3.1.5 Outline the thermal, cohesive, and solvent properties of water  3.1.6 Explain the relationship between the properties of water and its uses in living organisms as a coolant, medium for metabolic reactions, and transport medium. | | |
| 2.A.3b | Surface area-to-volume ratio s affect a biological system's ability to obtain necessary resources or eliminate waste products | | 2.1.6 Explain the importance of the surface area to volume ratio as a factor limiting cell size. | | |
| 2.A.3b1 | As cells increase in volume, the relative surface area decreases and demand for material resources increases; more cellular structures are necessary to adequately exchange materials and energy with the environment. These limitations restrict cell size. (*Example: root hairs; cells of alveoli; cells of the villi; microvilli)* | | 6.1.7 Explain how the structure of the villus is related to its role in absorption and transport of the products of digestion. | | |
| 2.A.3b2 | The surface area of the plasma membrane must be large enough to adequately exchange materials; smaller cells have a more favorable surface area-to-volume ratio for exchange of materials with the environment. | |  | | |
| LO 2.6 | The student is able to use calculated surface area-to-volume ratios to predict which cell(s) might eliminate wastes or procure nutrients faster by diffusion. | |  | | |
| LO2.7 | Students will be able to explain how cell size and shape affect the overall rate of nutrient intake and the rate of waste elimination | |  | | |
| LO2.8 | The student is able to justify the selection of data regarding the types of molecules that an animal, plant or bacterium will take up as necessary building blocks and excrete as waste products | |  | | |
| LO2.9 | The student is able to represent graphically or model quantitatively the exchange of molecules between an organism and its environment, and the subsequent use of these molecules to build new molecules that facilitate dynamic homeostasis, growth and reproduction. | | 6.5.8 State that homeostasis involves maintaining the internal environment between limits, including blood pH, carbon dioxide concentration, blood glucose concentration, body temperature, and water balance.  6.5.9 Explain that homeostasis involves monitoring levels of variables and correcting changes in levels by negative feedback mechanisms. | | |
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| **2.B.1 Cell membranes are selectively permeable due to their structure** | | | | | |
| 2.B.1a | Cell membranes separate the internal environment of the cell from the external environment | | | |  |
| 2.B.1b | Selective permeability is a direct consequence of membrane structure, as described by the fluid mosaic model | | | |  |
| 2.B.1b1 | Cell membranes consist of a structural framework of phospholipid molecules, embedded proteins, cholesterol, glycoproteins, and glycolipids | | | | 2.3.6 Outline two roles of extracellular components *Animal cells secrete glycoproteins that form the extracellular matrix. This functions in support, adhesion, and movement.*  2.4.1 |
| 2.B.1b2 | Phospholipids give the membrane both hydrophilic and hydrophobic properties. The hydrophilic phosphate portions of the phospholipids are oriented toward the aqueous external or internal environments, while the hydrophobic fatty acid portions face each other within the interior of the membrane itself | | | | 2.4.2 Explain how the hydrophobic and hydrophilic properties of phospholipids help to maintain the structure of cell membranes |
| 2.B.1b3 | Embedded proteins can be hydrophilic, with charged and polar side groups, or hydrophobic, with nonpolar side groups | | | |  |
| 2.B.1b4 | Small, uncharged polar molecules and small nonpolar molecules, such as N2, freely pass across the membrane. Hydrophilic substances such as large polar molecules and ions move across the membrane through embedded channel and transport proteins. Water moves across membranes and through channel proteins called aquaporins. | | | |  |
| 2.B.1c | Cell walls provide a structural boundary, as well as permeability barrier for some substances to the internal environments | | | | 2.3.6 Outline two roles of extracellular components *The plant cell wall maintains cell shape, prevents excessive water uptake, and holds the whole plant up against the force of gravity* |
| 2.B.1c1 | Plant cell walls are made of cellulose and are external to the cell membrane | | | | 2.3.5 State three differences between plant and animal cells |
| 2.B.1c2 | Other examples are cell walls of prokaryotes and fungi | | | |  |
| LO2.10 | The student is able to use representations and models to pose scientific questions about the properties of cell membranes and selective permeability based on molecular structure. | | | |  |
| LO2.11 | The student is able to construct models that connect the movement of molecules across membranes with membrane structure and function. | | | | 2.4.1 Draw and label a diagram to show the structure of membranes IB says, *The digram should show the phospholipid bilayer, cholesterol, glycoproteins, and integal and peripheral proteins. Integral proteins are embedded in the phospholipids of the membrane, whereas peripheral proteins are attached to its surface*. |
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| **2.B.2 Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes** | | | | | |
| 2.B.2a | Passive transport does not require the input of metabolic energy; the net movement of molecules is from high concentration to low concentration | | | |  |
| 2.B.2a1 | Passive transport plays a primary role in the import of resources and the export of wastes | | | | 2.4.4 Define *diffusion* and *osmosis*  *IB says: Diffusion is the passive movement of particles from a region of high concentration to a region of low concentration.*  *Osmosis is the passive movement of water molecules, across a partially permeable membrane, from a region of lower solute concentration to a region of higher solute concentration.* |
| 2.B.2a2 | Membrane proteins play a role in facilitated diffusion of charged and polar molecules through a membrane *(Example: Glucose transport; Na+/K+ transport) (Exclusion: There is no particular membrane protein that is required for teaching this concept)* | | | | 2.4.3 List the functions of membrane proteins IB says, *Include the following: hormone binding sites, immobilized enzymes, cell adhesion, cell-to-cell communication, channels for passive transport, and pumps for active transport*  2.4.5 Explain passive transport across membranes by simple diffusion and facilitated diffusion |
| 2.B.2a3 | External environments can be hypotonic, hypertonic, or isotonic to internal environments of cells | | | |  |
| 2.B.2b | Active transport requires free energy to move molecules from regions of low concentration to regions of high concentration | | | | 2.4.6 Explain the role of protein pumps and ATP in active transport across membranes |
| 2.B.2b1 | Active transport is a process where free energy (often provided by ATP) is used by proteins embedded in the membrane to "move" molecules and/or ions across the membrane and to establish and maintain concentration gradients | | | |  |
| 2.B.2b2 | Membrane proteins are necessary for active transport | | | | 2.4.3 List the functions of membrane proteins IB says, *Include the following: hormone binding sites, immobilized enzymes, cell adhesion, cell-to-cell communication, channels for passive transport, and pumps for active transport*  2.4.6 Explain the role of protein pumps and ATP in active transport across membranes |
| 2.B.2c | The processes of endocytosis and exocytosis move large molecules from the external environment to the internal environment and vice versa, respectively | | | | 2.4.8 Describe how the fluidity of the membrane allows it to change shape, break and re-form during endocytosis and exocytosis |
| 2.B.2c1 | In exocytosis, internal vesicles fuse with the plasma membrane to secrete large macromolecules out of the cell | | | |  |
| 2.B.2c2 | In endocytosis, the cell takes in macromolecules and particulate matter by forming new vesicles derived from the plasma membrane | | | |  |
| LO2.12 | The student is able to use representations and models to analyze situations or solve problems qualitatively and quantitatively to investigate whether dynamic homeostasis is maintained by the active movement of molecules across membranes | | | |  |
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| **2.B.3 Eukaryotic cells maintain internal membranes that partition the cell into specialized regions** | | | | | |
| 2.B.3a | Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing surface area where reactions can occur | | |  | |
| 2.B.3b | Membranes and membrane-bound organelles in eukaryotic cells localize (compartmentalize) intracellular metabolic processes and specific enzymatic reactions. (*Examples: Endoplasmic reticulum, mitochondria, chloroplasts, Golgi, nuclear envelope)* | | |  | |
| 2.B.3c | Archaea and Bacteria generally lack internal membranes and organelles and have a cell wall | | | 2.3.4.5 *eukaryotic cells have internal membranes that compartmentalize their functions* | |
| LO 2.13 | The student is able to explain how internal membranes and organelles contribute to cell functions | | | 2.4.7 Explain how vesicles are used to transport materials within a cell between the rough endoplasmic reticulum, Golgi apparatus, and plasma membrane | |
| LO2.14 | The student is able to use representations and models to describe differences in prokaryotic and eukaryotic cells | | | 2.2.1 Draw and label a diagram of the ultrastructure of *Escherichia coli (E. coli)* as an example of a prokaryote.  2.2.2 Annotate the diagram from 2.2.1 with the functions of each named structure.  2.3.1 Draw and label a diagram of the ultrastructure of a liver cell as an example of an animal cell  2.3.2 Annotate the diagram from 2.3.1 with the functions of each named structure.  2.3.4 Compare prokaryotic and eukaryotic cells.  IB says: *Differences should include:*  *1. Naked DNA versus DNA associated with proteins*  *2. DNA in cytoplasm versus DNA enclosed in a nuclear envelope*  *3. no mitochondria versus mitochondria*  *4. 70s versus 80s ribosome*  *5. eukaryotic cells have internal membranes that compartmentalize their functions* | |
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| **2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes** | | | | | |
| 2.C.1a | Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point. *(Examples: operons in gene regulation; temperature regulation in animals; plant responses to water limitations)* | | | | 6.5.9 Explain that homeostasis involves monitoring levels of variables and correcting changes in levels by negative feedback mechanisms.  6.5.10 Explain the control of body temperature, including the transfer of heat in blood, and the roles of the hypothalamus, sweat glands, skin arterioles and shivering  6.5.11 Explain the control of blood glucose concentration, including the roles of glucagons, insulin, and α and β cells in the pancreatic islets  9.2.7 State that guard cells can regulate transpiration by opening and closing stomata.  9.2.8 State that the plant hormone abscisic acid causes the closing of stomata.  9.2.10 Outline four adaptations of xerophytes that help to reduce transpiration. |
| 2.C.1b | Positive feedback mechanisms amplify responses and processes in biological organisms. The variation initiating the response is moved farther away from the initial set-point. Amplification occurs when the stimulus is further activated which, in turn, initiates an additional response that produces system change. *(Examples: Lactation in mammals, onset of labor in childbirth, ripening of fruit)* | | | | 11.4.15 Outline the process of birth and its hormonal control, including the changes in progesterone and oxytocin levels and positive feedback. |
| 2.C.1c | Alteration in the mechanisms of feedback often results in deleterious consequences *(Examples: diabetes mellitus in response to decreased insulin; dehydration in response to decreased antidiuretic hormone; Graves' disease; blood clotting)* | | | | 6.5.12 Distinguish between Type I and Type II diabetes |
| LO2.15 | The student can justify a claim made about the effects on a biolgoical system at the molecular, physiological, or organismal level when given a scenario in which one or more components within a negative regulatory system is altered. | | | |  |
| LO2.16 | The student is able to connect how organisms use negative feedback to maintain their internal environments. | | | |  |
| LO2.17 | The student is able to evaluate data that show the effect(s) of changes in concentrations of key molecules on negative feedback mechanisms. | | | |  |
| LO2.18 | The student can make predictions about how organisms use negative feedback mechanisms to maintain their internal environment | | | |  |
| LO2.19 | The student is able to make predictions about how positive feedback mechanisms amplify activities and processes in organisms based on scientific theories and models. | | | |  |
| LO2.20 | The student is able to justify that positive feedback mechanisms amplify responses in organisms | | | |  |
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| **2.C.2 Organisms respond to changes in their external environments** | | | | | |
| 2.C.2a | Organisms respond to changes in their environment through behavioral and physiological mechanisms. *Examples: Photoperiodism and phototropism in plants; hibernation and migration in animals; taxis and kinesis in animals; chemotaxis in bacteria, sexual reproduction in fungi; noctural and diurnal activity, circadian rhythms; shivering and sweating in humans. No specific behavioral or physiological mechanism is required for teaching the above concept. Teachers are free to choose the mechanism that best fosters student understanding.* | | | | E.6.6 State that animals show rhythmical variations in activity.  E.6.7 Outline two examples illustrating the adaptive value of rhythmical behaviour patterns |
| LO2.21 | The student is able to justify the selection of the kind of data needed to answer scientific questions about the relevant mechanism that organisms use to respond to changes in their external environment. | | | |  |
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| **2.D.1 All biological systems from cells and organisms to populations, communities, and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy** | | | | | |
| 2.D.1a | Cell activities are affected by interactions with biotic and abiotic factors (*examples: cell density, biofilms, temperature, water availability, sunlight)* | | | |  |
| 2.D.1b | Organism activities are affected by interactions with biotic and abiotic factors (*examples: symbiosis, predator-prey relationships, water and nutrient availability, temperature, salinity, pH)* | | | | 3.6.3 Explain the effects of temperature, pH, and substrate concentration on enzyme activity  3.8.8 Outline the effects of temperature, light intensity, and carbon dioxide concentration on the rate of photosynthesis.  9.2.9 Explain how the abiotic factors light, temperature, wind and humidity, affect the rate of transpiration in a typical terrestrial plant. |
| 2.D.1c | The stability of populations, communities and ecosystems is affected by interactions with biotic and abiotic factors. *(Examples: Water and nutrient availability, availability of nesting materials and sites, food chains and food webs, species diversity, population density, algal blooms)* | | | | 5.1.1 Define *species, habitat, population,community, ecosystem,* and *ecology*  *IB says:*  *Species: A group of organisms that can interbreed and produce fertile offspring*  *Habitat: the environment in which a species normally lives or the location of a living organism*  *Population: a group of organisms of the same species who live in the same area at the same time*  *Community: a group of populations living and interacting with each other in the same area*  *Ecosystem: a community and its abiotic environment*  *Ecology: the study of relationships between living organisms and between organisms and their environement* |
|  | *Exclusion: No specific example is required for teaching the above concepts. Teachers are free to choose an example that best fosters student understanding.* | | | |  |
| LO2.22 | The student is able to refine scientific models and questions about the effect of complex biotic and abiotic interactions on all biological systems, from cells and organisms to populations, communities, and ecosystems | | | |  |
| LO2.23 | The student is able to design a plan for collecting data to show that all biological systems (cells, organisms, populations, communities, and ecosystems) are affected by complex biotic and abiotic interactions | | | |  |
| LO2.24 | The student is able to analyze data to identify possible patterns and relationships between a biotic or abiotic factor and a biological system (cells, organisms, populations, communities, or ecosystems) | | | |  |
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| **2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation to different environments** | | | | | |
| 2.D.2a | Continuity of homeostatic mechanisms reflects common ancestry, while changes may occur in response to different environmental conditions | | | |  |
| 2.D.2b | Organisms have various mechanisms for obtaining nutrients and eliminating wastes (*examples: gas exchange in aquatic and terrestrial plants; digestive mechanisms in animals such as food vacuoles, gastrovascular cavities, one-way digestive systems; respiratory systems of aquatic and terrestrial animals; nitrogenous waste production and elimination in aquatic and terrestrial animals)* | | | | 6.1 |
| 2.D.2c | Homeostatic control systems in species of microbes, plants and animals support common ancestry. *(Examples: excretory systems in flatworms, earthworms and vertebrates; osmoregulation in bacteria, fish, and protists; osmoregulation in aquatic and terrestrial plants; circulatory systems in fish, amphibians, and mammals; thermoregulation in aquatic and terrestrial animals)* | | | | 6.5 |
| LO2.25 | The student can construct explanations based on scientific evidence that homeostatic mechanisms reflect continuity due to common ancestry and/or divergence due to adaptation in different environments | | | |  |
| LO2.26 | The student is able to analyze data to identify phylogenetic patterns or relationships, showing that homeostatic mechanisms reflect both continuity due to common ancestry and change due to evolution in different environments | | | |  |
| LO2.27 | The student is able to connect differences in the environment with the evolution of homeostatic mechanisms | | | |  |
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| **2.D.3 Biological systems are affected by disruptions to their dynamic homeostasis** | | | | | |
| 2.D.3a | Disruption at the molecular and cellular levels affect the health of the organism (*examples: physiological responses to toxic substances; dehydration; immunological responses to pathogens, toxins, and allergens)* | | | | 6.3 and 11.1 |
| 2.D.3b | Disruptions to ecosystems impact the dynamic homeostasis or balance of the ecosystems *(Examples: invasive and/or eruptive species; human impact; hurricanes, floods, volcanoes, fires; water limitation; salination)* | | | | 5.2.3, 5.2.6 |
| LO2.28 | The student is able to use representations or models to analyze quantitatively and qualitatively the effects of disruptions to dynamic homeostasis in biological systems | | | |  |
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| **2.D.4 Plants and animals have a variety of chemical defenses against infections that affect dynamic homeostasis** | | | | | |
| 2.D.4a | Plants, invertebrates and vertebrates have multiple, non-specific immune responses *(Examples: invertebrate immune systems have nonspecific response mechanisms, but they lack pathogen-specific deference responses; plant defenses against pathogens include molecular recognition systems with system responses--infection triggers chemical responses that destroy infected and adjacent cells; vertebrate immune systems have nonspecific and nonheritable defense mechanisms against pathogens)* | | | | 6.3.1 Define *pathogen*  6.3.3 Outline the role of skin and mucous membranes in defence against pathogens. |
| 2.D.4b | Mammals use specific immune responses triggered by natural or artificial agents that disrupt dynamic homeostasis | | | |  |
| 2.D.4b1 | The mammalian immune system includes two types of specific responses: cell mediated and humoral | | | |  |
| 2.D.4b2 | In the cell-mediated response, cytotoxic T cells, a type of lymphocytic white blood cell, "target" intracellular pathogens when antigens are displayed on the outside of cells. | | | | 6.3.4 Outline how phagocytotic leucocytes ingest pathogens in the blood and in body tissues. **Different wording?** |
| 2.D.4b3 | In the humoral response, B cells, a type of lymphocytic white blood cell, produce antibodies against specific antigens | | | | 6.3.5 Distinguish between *antigens* and *antibodies*  6.3.6 Explain antibody production |
| 2.D.4b4 | Antigens are recognized by antibodies to the antigen | | | |  |
| 2.D.4b5 | Antibodies are proteins produced by B cells, and each antibody is specific to a particular antigen | | | | 11.1.4 Explain antibody production  *IB says: Limit the explanation to antigen presentation by macrophages and activation of helper T-cells leading to activation of B-cells which divide to form clones of antibody-secreting plasma cells and memory cells.* |
| 2.D.4b6 | A second exposure to an antigen results in a more rapid and enhanced immune response | | | | 11.1.2 Outline the principle of challenge and response, clonal selection and memory cells as the basis of immunity.  11.1.3 Define *active* and *passive* immunity  11.1.6 Explain the principle of vaccination *IB says: Emphasize the role of memory cells. The primary and secondary responses can be clearly illustrated by a graph. Precise details of all the types of vaccine (attenuated virus, inactivated toxins, and so on) for specific diseases are not required.`* |
|  | *Exclusion: Memorization of the structures of specific antibodies* | | | |  |
| LO2.29 | The student can create representations and models to describe immune responses | | | |  |
| LO2.30 | The student can create representations or models to describe nonspecific immune defenses in plants and animals | | | |  |
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| **2.E.1 Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms** | | | | | |
| 2.E.1a | Observable cell differentiation results from the expression of genes for tissue-specific proteins | | | | 2.1.8 Explain that cells in multicellular organisms differentiate to carry out specialized functions by expressing some of their genes but not others  2.1.9 State that stem cells retain the capacity to divide and have the ability to differentiate along different pathways |
| 2.E.1b | Induction of transcription factors during development results in sequential gene expression | | | |  |
| 2.E.1b1 | Homeotic genes are involved in developmental patterns and sequences | | | |  |
| 2.E.1b2 | Embryonic induction in development results in the correct timing of events | | | |  |
| 2.E.1b3 | Temperature and the availability of water determine seed germination in most plants | | | | 9.3.4 Explain the conditions needed for the germination of a typical seed. |
| 2.E.1b4 | Genetic mutations can result in abnormal development | | | | 4.1.3, 4.1.4 |
| 2.E.1b5 | Genetic transplantation experiments support the link between gene expression and normal development | | | |  |
| 2.E.1b6 | Genetic regulation by microRNAs plays an important role in the development of organisms and the control of cellular functions | | | |  |
| 2.E.1c | Programmed cell death (apoptosis) plays a role in normal development and differentiation *(Example: Morphogenesis of fingers and toes; immune function; c. elegans development; flower development)* | | | |  |
|  | *Exclusion: Names of the specific stages of embryonic development* | | | |  |
| LO2.31 | The student can connect concepts in and across domains to show that timing and coordination of specific events are necessary for normal development in an organism and that these events are regulated by multiple mechanisms | | | |  |
| LO2.32 | The student is able to use a graph or diagram to analyze situations or solve problems (quantitatively or qualitatively) that involve timing and coordination of events necessary for normal development in an organisms | | | |  |
| LO2.33 | The student is able to justify scientific claims with scientific evidence to show that timing and coordination of several events are necessary for normal development in an organism and that these events are regulated by multiple mechanisms | | | |  |
| LO2.34 | The student is able to describe the role of programmed cell death in development and differentiation, the reuse of molecules, and the maintenance of dynamic homeostasis. | | | |  |
|  |  | | | |  |
| **2.E.2 Timing and coordination of physiological events are regulated by multiple mechanisms** | | | | | |
| 2.E.2a | In plants, physiological events involve interactions between environmental stimuli and internal molecular signals | | | |  |
| 2.E.2a1 | Phototropism, or the response to light | | | | 9.1.7 Explain the role of auxin in phototropism as an example of the control of plant growth. |
| 2.E.2a2 | Photoperiodism, or the response to change in length of the night, that results in the flowering in long-day and short-day plants | | | | 9.3.6 Explain how flowering is controlled in long-day and short-day plants, including the role of phytochrome. |
|  | *Exclusion: Memorization of the names, molecular structures, and specific effects of all plant hormones* | | | |  |
| 2.E.2b | In animals, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues *Examples: circadian rhythms; diurnal/noctural and sleep/wake cycles; jet lag in humans; seasonal responses, such as hibernation, estivation, and migration; release and reaction to pheromones; visual displays in the reproductive cycle* | | | | E.6.6, E.6.7 |
| 2.E.2c | In fungi, protists and bacteria, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues *Examples: Fruiting body formation in fungi, slime molds, and certain types of bacteria; Quorum sensing in bacteria* | | | |  |
|  | *Exclusion: Memorization of the names, molecular structures and specific effects of hormones or features of the brain responsible for these physiological phenomena* | | | |  |
| LO2.35 | The student is able to design a plan for collecting data to support the scientific claim that timing and coordination of physiological events involve regulation | | | |  |
| LO2.36 | The student is able to justify scientific claims with evidence to show how timing and coordination of physiological events involve regulation | | | |  |
| LO2.37 | The student is able to connect concepts that describe mechanisms that regulate the timing and coordination of physiological events | | | |  |
|  |  | | | |  |
| **2.E.3 Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection** | | | | | |
| 2.E.3a | Individuals can act on information and communicate it to others | | | |  |
| 2.E.3a1 | Innate behaviors are behaviors that are inherited | | | | E.3.1 |
| 2.E.3a2 | Learning occurs through interactions with the environment and other organisms | | | | E.3.5 Outline Pavlov’s experiments into conditioning of dogs  E.3.6 Outline the role of inheritance and learning in the development of birdsong in young birds |
| 2.E.3b | Responses to information and communication of information are vital to natural selection | | | |  |
| 2.E.3b1 | In phototropism in plants, changes in the light source lead to differential growth, resulting in maximum exposure of leaves to light for photosynthesis | | | | 9.1.7 |
| 2.E.3b2 | In photoperiodism in plants, changes in the length of night regulate flowering and preparation for winter | | | | 9.3.6 |
| 2.E.3b3 | Behaviors in animals are triggered by environmental cues and are vital to reproduction, natural selection and survival *Examples: hibernation, estivation, migration, courtship* | | | | E.1.4 |
| 2.E.3b4 | Cooperative behavior within or between populations contributes to the survival of populations. *Examples: Availability of resources leading to fruiting body formation in fungi and certain types of bacteria; niche and resource partitioning; mutualistic relationships; biology of pollination* | | | | E.6.3 |
| LO2.38 | The student is able to analyze data to support the claim that responses to information and communication of information affect natural selection | | | |  |
| LO2.39 | The student is able to justify scientific claims, using evidence, to describe how timing and coordination of behavioral events in organisms are regulated by several mechanisms | | | |  |
| LO2.40 | The student is able to connect concepts in and across domains to predict how environmental factors affect responses to information and change behavior | | | |  |
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| **3.A.1 DNA, and in some cases RNA, is the primary source of heritable information** | | | | | |
| 3.A.1a | Genetic information is transmitted from one generation to the next through DNA or DNA | |  | | |
| 3.A.1a1 | Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules | |  | | |
| 3.A.1a2 | Noneukaryotic organisms have circular chromosomes, while eukaryotic organisms have multiple linear chromosomes, although in biology there are exceptions to this rule | | 4.1.1 State that eukaryote chromosomes are made of DNA and proteins | | |
| 3.A.1a3 | Prokaryotes, viruses and eukaryotes can contain plasmids, which are small extra-chromosomal, double-stranded circular DNA molecules | | 4.8.8 Outline a basic technique used for gene transfer involving plasmids, a host cell (bacterium, yeast or other cell), restriction enzymes (endonucleases), and DNA ligase | | |
| 3.A.1a4 | The proof that DNA is the carrier of genetic information involved a number of important historical experiments. These include: i. Contributions of Watson, Crick, Wilkins, and Franklin on the structure of DNA; ii. Avery-McLeod-McCarty experiments; iii. Hershey-Chase experiments | |  | | |
| 3.A.1a5 | DNA replication ensures continuity of hereditary information | |  | | |
| 3.A.1a5i | Replication is a semiconservative process; that is, one strand serves as the template for a new, complementary strand | | 3.4.3 State that DNA replication is semi-conservative | | |
| 3.A.1a5ii | Replication requires DNA polymerase plus many other essential cellular enzymes, occurs bidirectionally, and differs in the production of leading and lagging strands | | 3.4.1 Explain DNA replication in terms of unwinding the double helix and separation of the strands by helicase, followed by the formation of new complementary strands by DNA polymerase.  7.2.2 Explain the process of DNA replication in prokaryotes, including the role of enzymes (helicase, DNA polymerase, RNA primase, and DNA ligase), Okazaki fragments, and deoxynucleoside triphosphates.  7.2.3 State that DNA replication is initiated at many points in eukaryotic chromosomes. | | |
| 3.A.1a6 | Genetic information in retroviruses is a special case and has an alternate flow of information: from RNA to DNA, made possible by reverse transcriptase, an enzyme that copies the viral RNA genome into DNA. This DNA integrates into the host genome and becomes transcribed and translated for the assembly of new viral progeny. | |  | | |
|  | *Exclusion: The names of the steps and particular enzymes involved, beyond DNA polymerase, ligase, RNA polymerase, helicase, and topoisomerase, are outside the scope of the course* | |  | | |
| 3.A.1b | DNA and RNA molecules have structural similarities and differences that define function | |  | | |
| 3.A.1b1 | Both have three components--sugar, phosphate, and a nitrogenous base--which form nucleotide units that are connected by covalent bonds to form a linear molecule with 3' and 5' ends, with the nitrogenous bases perpendicular to the sugar-phosphate backbone | | 3.3.1 Outline DNA nucleotide structure in terms of sugar (deoxyribose), base, and phosphate.  3.3.3 Outline how DNA nucleotides are linked together by covalent bonds into a single strand  3.3.4 Explain how a DNA double helix is formed using complementary base pairing and hydrogen bonds.  7.1.1 Describe the structure of DNA, including the antiparallel strands, 3’ to 5’ linkages and hydrogen bonding between purines and pyrimidines *IB says: The 5’ end of the free DNA nucleotide is added to the 3’ end of the chain of nucleotides that is already synthesized.* | | |
| 3.A.1b2 | The basic structural differences include: i. DNA contains deoxyribose (RNA contains ribose); ii. RNA contains uracil in lieu of thymine in DNA; iii. DNA is usually double-stranded, RNA is usually single-stranded; iv. The two DNA strands in double-stranded DNA are antiparallel in directionality | | 3.5.1 Compare the structure of RNA and DNA | | |
| 3.A.1b3 | Both DNA and RNA exhibit specific nucleotide base pairing that is conserved through evolution: adenine pairs with thymine or uracil (A-T or A-U) and cytosine pairs with guanine (C-G). i. Purines (G and A) have a double ring structure. ii. Pyrimidines (C, T and U) have a single-ring structure. | | 3.2.2 State the names of the four base pairs of DNA  3.4.2 Explain the significance of complementary base pairing in the conservation of the base sequence of DNA | | |
| 3.A.1b4 | The seuqence of the RNA bases, together with the structure of the RNA molecule, determine RNA function.  i. mRNA carries information from the DNA to the ribosome  ii. tRNA molecules bind specific amino acids and allow information in the mRNA to be translated to a linear peptide sequence  iii. rRNA molecules are the functional building blocks of ribosomes  iv. The role of RNAi includes regulation of gene expression at the level of mRNA transcription | | 3.5.2 Outline DNA transcription in terms of the formation of an RNA strand complementary to the DNA strand by RNA polymerase  3.5.5 Discuss the relationship between one gene and one polypeptide. | | |
| 3.A.1c | Genetic information flows from a sequence of nucleotides in a gene to a sequence of amino acids in a protein | |  | | |
| 3.A.1c1 | The enzyme RNA-polymerase reads the DNA molecule in the 3' to 5' direction and synthesizes complementary mRNA molecules that determine the order of amino acids in the polypeptide | | 7.3.1 State that transcription is carried out in a 5’ 🡪 3’ direction.  7.3.3 Explain the process of transcription in prokaryotes, including the role of the promoter region, RNA polymerase, nucleoside triphosphates, and the terminator | | |
| 3.A.1c2 | In eukaryotic cells the mRNA transcript undergoes a series of enzyme-regulated modifications *(Examples: addition of a poly-A tail; addition of a GTP cap; excision of introns)* | | 7.1.5 State that eukaryotic genes can contain exons and introns.  7.3.4 State that eukaryotic RNA needs the removal of introns to form mature mRNA | | |
| 3.A.1c3 | Translation of the mRNA occurs in the cytoplasm on the ribosome | |  | | |
| 3.A.1c4 | In prokaryotic organisms, transcription is coupled to translation of the message. Translation involves energy and many steps, including initiation, elongation, and termination.  i. The mRNA interacts with the rRNA of the ribosome to initiate translation at the (start) codon  ii. The sequence of nucleotides on the mRNA is read in triplets called codons  iii. Each codon encodes a specific amino acid, which can be deduced by using a genetic code chart. Many amino acids have more than one codon. (*Exclusion: Memorization of the genetic code.)*  iv. tRNA brings the correct amino acid to the correct place on the mRNA  v. The amino acid is transferred to the growing peptide chain  vi. The process continues along the mRNA until a "stop" codon is reached  vii. The process terminates by release of the newly synthesized peptide/protein | | 3.5.3 Describe the genetic code in terms of codons composed of triplets of bases.  3.5.4 Explain the process of translation, leading to polypeptide formation. IB says: *Include the roles of messenger RNA (mRNA), transfer RNA (tRNA), codons, anticodons, ribosomes and amino acids.*  7.4.3 State that translation consists of initiation, elongation, translocation, and termination.  7.4.4 State that translation occurs in a 5’ 🡪 3’ direction.  7.4.6 Explain the process of translation, including ribosomes, polysomes, start codons and stop codons | | |
|  | *Exclusion: The details and names of the enyzmes and factors involved in each of these steps.* | |  | | |
| 3.A.1d | Phenotypes are determined through protein activities *(Examples: enzymatic reactions, transport by proteins, synthesis, degradation)* | |  | | |
| 3.A.1e | Genetic engineering techniques can manipulate the heritable information of DNA and, in special cases, RNA *(Examples: Electrophoresis, plasmid-based transformation, restriction enzyme analysis of DNA, polymerase chain reaction (PCR))* | | 4.4.1 Outline the use of polymerase chain reaction (PCR) to copy and amplify minute quantities of DNA  4.4.2 State that, in gel electrophoresis, fragments of DNA move in an electric field and are separated according to their size.  4.4.3 State that gel electrophoresis of DNA is used in DNA profiling  4.4.4 Describe the application of DNA profiling to determine paternity and also in forensic investigations.  4.4.5 Analyse DNA profiles to draw conclusions about paternity or forensic investigations  4.4.8 Outline a basic technique used for gene transfer involving plasmids, a host cell (bacterium, yeast or other cell), restriction enzymes (endonucleases), and DNA ligase  4.4.9 State two examples of the current uses of genetically modified crops or animals.  4.4.10 Discuss the potential benefits and possible harmful effects of one example of genetic modification  4.4.11 Define *clone*  4.4.12 Outline a technique for cloning using differentiated animal cells  4.4.13 Discuss the ethical issues of therapeutic cloning in humans | | |
| 3.A.1f | *Examples of products of genetic engineering include: Genetically modified foods, transgenic animals, cloned animals; pharmaceuticals such as human insulin or factor X* | |  | | |
| LO3.1 | The student is able to construct scientific explanations that use the structures and mechanisms of DNA and RNA to support the claim that DNA and, in some cases, that RNA are the primary sources of heritable information | |  | | |
| LO3.2 | The student is able to justify the selection of data from historical investigations that support the claim that DNA is the source of heritable information | |  | | |
| LO3.3 | The student is able to describe representations and models that illustrate how genetic information is copied for transmission between generations | |  | | |
| LO3.4 | The student is able to describe representations and models illustrating how genetic information is translated into polypeptides | |  | | |
| LO3.5 | The student can justify the claim that humans can manipulate heritable information by identifying *at least two* commonly used technologies | |  | | |
| LO3.6 | The student can predict how a change in a specific DNA or RNA sequence can result in changes in gene expression | |  | | |
|  |  | |  | | |
| **3.A.2 In eukaryotes, heritable information is passed on to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization** | | | | | |
| 3.A.2a | The cell cycle is a complex set of stages that is highly regulated with checkpoints, which determine the ultimate fate of the cell | | | |  |
| 3.A.2a1 | Interphase consists of three phases: growth, synthesis of DNA, preparation for mitosis | | | | 2.5.1 Outline the stages in the cell cycle, including interphase (G1, S, G2), mitosis, and cytokinesis **Different in AP and IB!!**  2.5.3 State that interphase is an active period in the life of the cell when many metabolic reactions occur, including protein synthesis, DNA replication and an increase in the number of mitochondria and/or chloroplasts |
| 3.A.2a2 | The cell cycle is directed by internal controls or checkpoints. Internal and external signals provide stop-and-go signs at the checkpoints. *Examples: mitosis-promoting factor; action of platelet-derived growth factor; cancer results from disruptions in cell cycle control* | | | | 2.5.2 State that tumours (cancers) are the result of uncontrolled cell division and that these can occur in any organ or tissue |
| 3.A.2a3 | Cyclins and cylin-dependent kinases control the cell cycle. *Exclusion: knowledge of any one cyclin-CdK pair or growth factor.* | | | |  |
| 3.A.2a4 | Mitosis alternates with interphase in the cell cycle | | | |  |
| 3.A.2a5 | When a cell specializes, it often enters into a stage where it no longer divides, but it can reenter the cell cycle when given appropriate cues. Nondividing cells may exit the cell cycle; or hold at a particular stage in the cell cycle | | | |  |
| 3.A.2b | Mitosis passes a complete genome from the parent cell to daughter cells | | | |  |
| 3.A.2b1 | Mitosis occurs after DNA replication | | | |  |
| 3.A.2b2 | Mitosis followed by cytokinesis produces two genetically identical daughter cells | | | | 2.5.5 Explain how mitosis produces two genetically identical nuclei |
| 3.A.2b3 | Mitosis plays a role in growth, repair, and asexual reproduction | | | | 2.5.6 State that growth, embryonic development, tissue repair, and asexual reproduction involve mitosis |
| 3.A.2b4 | Mitosis is a continuous process with observable structural features along the mitotic process. Evidence of student learning is demonstrated by knowing the order of the processes (replication, alignment, separation.) *Exclusion: Memorization of the names of the phases of mitosis.* | | | | 2.5.4 Describe the events that occur in the four phases of mitosis (prophase, metaphase, anaphase, and telophase)  IB says *Include supercoiling of chromosomes, attachment of spindle microtubules to centromeres, splitting of centromeres, movement of sister chromosomes to opposite poles, and breakage and re-formation of nuclear membranes.*  **Different in AP and IB!!** |
| 3.A.2c | Meiosis, a reduction division, followed by fertilization ensures genetic diversity in sexually reproducing organisms | | | | 4.2.1 State that meiosis is a reduction division of a diploid nucleus to form haploid nuclei |
| 3.A.2c1 | Meiosis ensures that each gamete receives one complete haploid (1n) set of chromosomes | | | |  |
| 3.A.2c2 | During meiosis, homologous chromosomes are paired, with one homologue originating from the maternal parent and the other from the paternal parent. Orientation of the chromosome pairs is random with respect to the cell poles. | | | |  |
| 3.A.2c3 | Separation of the homologous chromosomes ensures that each gamete receives a haploid (1n) set of chromosomes composed of both maternal and paternal chromosomes. | | | | 4.2.2 Define *homologous chromosomes* |
| 3.A.2c4 | During meiosis, homologous chromatids exchange genetic material via a process called "crossing over", which increases genetic variation in the resultant gametes. | | | | 10.1.3 Explain how meiosis results in an effectively infinite genetic variety in gametes through crossing over in prophase I and random orientation in metaphase I.  10.1.5 Explain the relationship between Mendel’s law of independent assortment and meiosis  10.2.3 Explain how crossing over between non-sister chromatids of a homologous pair in prophase I can result in an exchange of the alleles |
| 3.A.2c5 | Fertilization involves the fusion of two gametes, increases genetic variation in populations by providing for new combinations of genetic information in the zygote, and restores the diploid number of chromosomes. | | | | 11.4.9 Describe the process of fertilization, including the acrosome reaction, penetrating of the egg membrane by a sperm and the cortical reaction |
| LO3.7 | The student can make predictions about natural phenomena occurring during the cell cycle | | | |  |
| LO3.8 | The student can describe the events that occur in the cell cycle | | | | 4.2.3 Outline the process of meiosis, including pairing of homologous chromosomes and crossing over, followed by two divisions, which results in four haploid cells  10.1.1 Describe the behavior of the chromosomes in the phases of meiosis  10.1.2 Outline the formation of chiasmata in the process of crossing over |
| LO3.9 | The student is able to construct an explanation, using visual representations or narratives, as to how DNA in chromosomes is transmitted to the next generation via mitosis, or meiosis followed by fertilization | | | |  |
| LO3.10 | The student is able to represent the connection between meiosis and increased genetic diversity necessary for evolution | | | |  |
| LO3.11 | The student is able to evaluate evidence provided by data sets to support the claim that heritable information is passed from one generation to another generation through mitosis, or meiosis followed by fertilization | | | |  |
|  |  | | | |  |
| **3.A.3 The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring** | | | | | |
| 3.A.3a | Rules of probability can be applied to analyze passage of single-gene traits from parent to offspring |  | | | |
| 3.A.3b | Segregation and independent assortment of chromosomes result in genetic variation | 10.1.3 Explain how meiosis results in an effectively infinite genetic variety in gametes through crossing over in prophase I and random orientation in metaphase I.  10.1.4 State Mendel’s law of independent assortment | | | |
| 3.A.3b1 | Segregation and independent assortment can be applied to genes that are on different chromosomes |  | | | |
| 3.A.3b2 | Genes that are adjacent and close to each other on the same chromosome tend to move as a unit; the probability that they will segregate as a unit is a function of the distance between them | 10.2.4 Define linkage group  10.2.5 Explain an example of a cross between two linked genes  10.2.6 Identify which of the offspring are recombinants in a dihybrid cross involving linked genes | | | |
| 3.A.3b3 | The pattern of inheritance (monohybrid, dihybrid, sex-linked, and genes linked on the same homologous chromosome) can often be predicted from data that gives the parent genotype/phenotype and/or the offspring phenotypes/genotypes | 4.1.2 Define *gene*, *allele*, and *genome*  4.3.1 Define *genotype, phenotype, dominant allele, recessive allele, codominant alleles, locus, homozygous, heterozygous, carrier* and *test cross.*  10.2.1 Calculate and predict the genotypic and phenotypic ratio of offspring of dihybrid crosses involving unlinked autosomal genes | | | |
| 3.A.3c | Certain human genetic disorders can be attributed to the inheritance of single gene traits or specific chromosomal changes, such as nondisjunction *Examples: Sickle cell anemia, Tay-Sachs disease, Huntington's disease, X-linked color blindness, Trisomy 21/Down syndrome, Klinefelter's syndrome* | 4.2.4 Explain that non-disjunction can lead to changes in chromosome number, illustrated by reference to Down syndrome (trisomy 21)  4.1.14 Explain the consequence of a base substitution mutation in relation to the processes of transcription and translation, using the example of sickle cell anemia | | | |
| 3.A.3d | Many ethical, social and medical issues surround human genetic disorders. *Examples: Reproductive issues, civic issues such as ownership of genetic information, privacy, historical contexts, etc.* | 4.4.6 Outline three outcomes of the sequencing of the complete human genome | | | |
| LO3.12 | The student is able to construct a representation that connects the process of meiosis to the passage of traits from parent to offspring |  | | | |
| LO3.13 | The student is able to pose questions about ethical, social or medical issues surrounding human genetic disorders |  | | | |
| LO3.14 | The student is able to apply mathematical routines to determine Mendelian patterns of inheritance provided by data sets | 4.3.2 Determine the genotypes and phenotypes of the offspring of a monohybrid cross using a Punnett grid  4.3.3 State that some genes have more than two alleles (multiple alleles)  4.3.11 Predict the genotypic and phenotypic ratios of offspring of monohybrid crosses involving any of the above patterns of inheritance  4.3.12 Deduce the genotypes and phenotypes of individuals in pedigree charts | | | |
|  |  |  | | | |
| **3.A.4 The inheritance pattern of many traits cannot be explained by simple Mendelian genetics** | | | | | |
| 3.A.4a | Many traits are the product of multiple genes and/or physiological processes. | |  | | |
| 3.A.4a1 | Patterns of inheritance of many traits do not follow ratios predicted by Mendel's laws and can be identified by quantitative analysis, where observed phenotypic ratios statistically differ from predicted ratios | |  | | |
| 3.A.4b | Some traits are determined by genes on sex chromosomes  *Examples:*  *Sex-linked genes reside on sex chromosomes (X in humans)*  *In mammals and flies, the Y chromosome is very small and carries few genes*  *In mammals and flies, females are XX and males are XY; as such, X-linked recessive traits are always expressed in males*  *Some traits are sex limited, and expression depends on the sex of the individual, such as milk production in female mammals and pattern baldness in males* | | 4.3.5 Explain how the sex chromosomes control gender by referring to the inheritance of X and Y chromosomes in humans  4.3.6 State that some genes are present on the X chromosome and absent from the shorter Y chromosome in humans  4.3.7 Define *sex linkage*  4.3.8 Describe the inheritance of colour blindness and hemophilia as examples of sex linkage  4.3.9 State that a human female can be homozygous or heterozygous with respect to sex-linked genes  4.3.10 Explain that female carriers are heterozygous for X-linked recessive alleles  10.2.2 Distinguish between autosomes and sex chromosomes | | |
| 3.A.4c | Some traits result from nonnuclear inheritance | |  | | |
| 3.A.4c1 | Chloroplasts and mitochondria are randomly assorted to gametes and daughter cells; thus, traits determined by chloroplast and mitochondrial DNA do not follow simple Mendelian rules | |  | | |
| 3.A.4c2 | In animals, mitochondrial DNA is transmitted by the egg and not by the sperm; as such, mitochondrial-determined traits are maternally inherited | |  | | |
|  | *Exclusions: Epistasis and pleiotropy* | |  | | |
| LO3.15 | The student is able to explain deviations from Mendel's model of the inheritance of traits | |  | | |
| LO3.16 | The student is able to explain how the inheritance patterns of many traits cannot be accounted for by Mendelian genetics | |  | | |
| LO3.17 | The student is able to describe representations of an appropriate example of inheritance patterns that cannot be explained by Mendel's model of the inheritance of traits | |  | | |
|  |  | |  | | |
| **3.B.1 Gene regulation results in differential gene expression, leading to cell specialization** | | | | | |
| 3.B.1a | Both DNA regulatory sequences, regulatory genes, and small regulatory RNAs are involved in gene expression | |  | | |
| 3.B.1a1 | Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription *Example: promoters, terminators, enhancers* | |  | | |
| 3.B.1a2 | A regulatory gene is a sequence of DNA encoding a regulatory protein or RNA | |  | | |
| 3.B.1b | Both positive and negative control mechanisms regulate gene expression in bacteria and viruses | |  | | |
| 3.B.1b1 | The expression of specific genes can be turned on by the presence of an inducer | |  | | |
| 3.B.1b2 | The expression of specific genes can be inhibited by the presence of a repressor | |  | | |
| 3.B.1b3 | Inducers and repressors are small molecules that interact with regulatory proteins and/or regulatory sequences | |  | | |
| 3.B.1b4 | Regulatory proteins inhibit gene expression by binding to DNA and blocking transcription (negative control) | |  | | |
| 3.B.1b5 | Regulatory proteins stimulate gene expression by binding to DNA and stimulating transcription (positive control) or binding to repressors to inactivate repressor function. | |  | | |
| 3.B.1b6 | Certain genes are continuously expressed; that is, they are always turned "on" (e.g. the ribosomal genes) | |  | | |
| 3.B.1c | In eukaryotes, gene expression is complex and control involves regulatory genes, regulatory elements, and transcription factors that act in concert | |  | | |
| 3.B.1c1 | Transcription factors bind to specific DNA sequences and/or other regulatory proteins | |  | | |
| 3.B.1c2 | Some of the transcription factors are activators (increase expression), while others are repressors (decrease expression) | |  | | |
| 3.B.1c3 | The combination of transcription factors binding to the regulatory regions at any one time determines how much, if any, of the gene product will be produced | |  | | |
| 3.B.1d | Gene regulation accounts for some of the phenotypic differences between organisms with similar genes | |  | | |
| LO3.18 | The student is able to describe the connection between regulation of gene expression and observed differences between different kinds of organisms | |  | | |
| LO3.19 | The student is able to describe the connection between the regulation of gene expression and observed differences between individuals in a population | |  | | |
| LO3.20 | The student is able to explain how the regulation of gene expression is essential for the processes and structures that support efficient cell function | |  | | |
| LO3.21 | The student can use representations to describe how gene regulation influences cell products and function. | |  | | |
|  |  | |  | | |
| **3.B.2 A variety of intercellular and intracellular signal transmissions mediate gene expression** | | | | | |
| 3.B.2a | Signal transmission within and between cells mediates gene expression.  *Examples:*  *Cytokines regulate gene expression to allow for cell replication and division*  *Mating pheromones in yeast trigger mating gene expression*  *Levels of cAMP regulate metabolic gene expression in bacteria*  *Expression of the SRY gene triggers the male sexual development pathway in animals*  *Ethylene levels cause changes in the production of different enzymes, allowing fruits to ripen*  *Seed germination and gibberellin* | | 9.3.5 Outline the metabolic processes during germination of a starchy seed. | | |
| 3.B.2b | Signal transmission within and between cells mediates cell function  *Examples:*  *Mating pheromones in yeast trigger mating genes expression and sexual reproduction*  *Morphogens stimulate cell differentiation and development*  *Changes in p53 activity can result in cancer*  *HOX genes and their role in development* | |  | | |
| LO3.22 | The student is able to explain how signal pathways mediate gene expression, including how this process can affect protein production | |  | | |
| LO3.23 | The student can use representations to describe mechanisms of the regulation of gene expression. | |  | | |
|  |  | |  | | |
| **3.C.1 Changes in genotype can result in changes in phenotype** | | | | | |
| 3.C.1a | Alterations in a DNA sequence can lead to changes in the type or amount of the protein produced and the consequent phenotype | | 4.1.3 Define *gene mutation*  4.1.4 Explain the consequence of a base substitution mutation in relation to the processes of transcription and translation, using the example of sickle cell anemia | | |
| 3.C.1a1 | DNA mutations can be positive, negative, or neutral based on the effect or lack of effect they have on the resulting nucleic acid or protein and the phenotypes that are conferred by the protein | |  | | |
| 3.C.1b | Errors in DNA replication or DNA repair mechanisms, and external factors, including radiation and reactive chemicals, can cause random changes, e.g., mutations in the DNA | |  | | |
| 3.C.1b1 | Whether or not a mutation is detrimental, beneficial, or neutral depends on the environmental context. Mutations are the primary source of genetic variation. | |  | | |
| 3.C.1c | Errors in mitosis or meiosis can cause changes in phenotype | |  | | |
| 3.C.1c1 | Changes in chromosome number often result in new phenotypes, including sterility caused by triploidy and increased vigor of other polyploids | | D.2.5 Explain how polyploidy can contribute to speciation | | |
| 3.C.1c2 | Changes in chromosome number often result in human disorders with developmental limitations, including Trisomy 21 (Down syndrome) and XO (Turner syndrome) | | 4.2.4 Explain that non-disjunction can lead to changes in chromosome number, illustrated by reference to Down syndrome (trisomy 21) | | |
| 3.C.1d | Changes in genotype may affect phenotypes that are subject to natural selection. Genetic changes that enhance survival and reproduction can be selected by environmental conditions.  *Example:*  *Antibiotic resistance mutations*  *Pesticide resistance mutations*  *Sickle cell disorder and heterozygote advantage* | | 5.4.7, 5.4.8 | | |
| 3.C.1d1 | Selection results in evolutionary change | |  | | |
| LO3.24 | The student is able to predict how a change in genotype, when expressed as a phenotype, provides a variation that can be subject to natural selection | |  | | |
| LO3.25 | The student can create a visual representation to illustrate how changes in a DNA nucleotide sequence can result in a change in the polypeptide produced | |  | | |
| LO3.26 | The student is able to explain the connection between genetic variations in organisms and phenotypic variations in populations | |  | | |
|  |  | |  | | |
| **3.C.2 Biological systems have multiple processes that increase genetic variation** | | | | | |
| 3.C.2a | The imperfect nature of DNA replication and repair increases variation | | |  | |
| 3.C.2b | The horizontal acquisitions of genetic information primarily in prokaryotes via transformation (uptake of naked DNA), tranduction (viral transmission of genetic information), conjugation (cell-to-cell transfer), and transposition (movement of DNA segments within and between DNA molecules) increase variation. *Exclusion: Details and specifics about the various processes.* | | | 4.8.8 Outline a basic technique used for gene transfer involving plasmids, a host cell (bacterium, yeast or other cell), restriction enzymes (endonucleases), and DNA ligase | |
| 3.C.2c | Sexual reproduction in eukaryotes involving gamete formation, including crossing-over during meiosis and the random assortment of chromosomes during meiosis, and fertilization serve to increase variation. Reproduction processes that increase genetic variation are evolutionarily conserved and are shared by various organisms. *Exclusion: The details of sexual reproduction cycles in various plants and animals are beyond the scope of the course. However, the similarities of the processes that provide for genetic variation are relevant and should be the focus of instruction.* | | | 10.1.3 Explain how meiosis results in an effectively infinite genetic variety in gametes through crossing over in prophase I and random orientation in metaphase I. | |
| LO3.27 | The student is able to compare and contrast processes by which genetic variation is produced and maintained in organisms from multiple domains. | | |  | |
| LO3.28 | The student is able to construct an explanation of the multiple processes that increase variation within a population. | | |  | |
|  |  | | |  | |
| **3.C.3 Viral replication results in genetic variation, and viral infection can introduce genetic variation into the hosts** | | | | | |
| 3.C.3a | Viral replication differs from other reproductive strategies and generates genetic variation via various mechanisms | | | |  |
| 3.C.3a1 | Viruses have highly efficient replicative capabilities that allow for rapid evolution and acquisition of new phenotypes | | | |  |
| 3.C.3a2 | Viruses replicate via a component assembly model allowing one virus to produce many progeny simultaneously via the lytic cycle | | | |  |
| 3.C.3a3 | Virus replication allows for mutations to occur through usual host pathways | | | |  |
| 3.C.3a4 | RNA viruses lack replication error-checking mechanisms, and thus have higher rates of mutation | | | |  |
| 3.C.3a5 | Related viruses can combine/recombine information if they infect the same host cell | | | |  |
| 3.C.3a6 | HIV is a well-studied system where the rapid evolution of a virus within the host contributes to the pathogenicity of viral infection | | | |  |
| 3.C.3b | The reproductive cycles of viruses facilitate transfer of genetic information | | | |  |
| 3.C.3b1 | Viruses transmit DNA or RNA when they infect a host cell *Examples: Transduction in bacteria; transposons present in incoming DNA* | | | |  |
| 3.C.3b2 | Some viruses are able to integrate into the host DNA and establish a latent (lysogenic) infection. These latent viral genomes can result in new properties for the host such as increased pathogenicity in bacteria. | | | |  |
| LO3.29 | The student is able to construct an explanation of how viruses introduce genetic variation in host organisms. | | | |  |
| LO3.30 | The student is able to use representations and appropriate models to describe how viral replication introduces genetic variation into a viral population. | | | |  |
|  |  | | | |  |
| **3.D.1 Cell communication processes share common features that reflect a shared evolutionary history** | | | | | |
| 3.D.1a | Communication involves transduction of stimulatory or inhibitory signals from other cells, organisms, or the environment | | | |  |
| 3.D.1b | Correct and appropriate signal transduction processes are generally under strong selective pressure | | | |  |
| 3.D.1c | In single-celled organisms, signal transduction pathways influence how the cell responds to its environment  *Examples:*  *Use of chemical messengers by microbes to communicate with other nearby cells and to regulate specific pathways in response to population density (quorum sensing)*  *Use of pheromones to trigger reproduction and developmental pathways*  *Response to external signals by bacteria that influences cell movement* | | | |  |
| 3.D.1d | In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole  *Examples:*  *Epinephrine stimulation of glycogen breakdown in mammals*  *Temperature determination of sex in some vertebrate organisms*  *DNA repair mechanisms* | | | |  |
| LO3.31 | The student is able to describe basic chemical processes for cell communication shared across evolutionary lines of descent | | | | 2.4.3 List the functions of membrane proteins IB says, *Include the following: hormone binding sites, immobilized enzymes, cell adhesion, cell-to-cell communication, channels for passive transport, and pumps for active transport* |
| LO3.32 | The student is able to generate scientific questions involving cell communication as it relates to the process of evolution | | | |  |
| LO3.33 | The student is able to use representation(s) and appropriate models to describe features of a cell-signalling pathway. | | | |  |
|  |  | | | |  |
| **3.D.2 Cells communicate with each other through direct contact with other cells or from a distance via chemical signalling** | | | | | |
| 3.D.2a | Cells communicate by cell-to-cell contact  *Examples:*  *Immune cells interact by cell-cell contact, antigen-presenting cells (APCs), helper T-cells, and killer T-cells*  *Plasmodesmata between plant cells that allow material to be transported from cell to cell* | | | | 11.1.4 Explain antibody production  *IB says: Limit the explanation to antigen presentation by macrophages and activation of helper T-cells leading to activation of B-cells which divide to form clones of antibody-secreting plasma cells and memory cells.* |
| 3.D.2b | Cells communicate over short distances by using local regulators that target cells in the vicinity of the emitting cell.  *Examples: Neurotransmitters*  *Plant immune response*  *Quorum sensing in bacteria*  *Morphogens in embryonic development* | | | | 6.5.6 Explain the principles of synaptic transmission. |
| 3.D.2c | Signals released by one cell type can travel long distances to target cells of another cell type. | | | |  |
| 3.D.2c1 | Endocrine signals are produced by endocrine cells that release signaling molecules, which are specific and can travel long distances through the blood to reach all parts of the body  *Examples: Insulin, human growth hormone, thyroid hormones, testosterone, estrongen. Exclusion: No specific system, with the exception of the endocrine system, is required for teaching these concepts.* | | | | 6.5.7 State that the endocrine system consists of glands that release hormones that are transported in the blood.  6.5.10 Explain the control of body temperature, including the transfer of heat in blood, and the roles of the hypothalamus, sweat glands, skin arterioles and shivering  6.5.11 Explain the control of blood glucose concentration, including the roles of glucagons, insulin, and α and β cells in the pancreatic islets |
| LO3.34 | The student is able to construct explanations of cell communication through cell-to-cell direct contact or through chemical signaling | | | |  |
| LO3.35 | The student is able to create representation(s) that depict how cell-to-cell communication occurs by direct contact or from a distance through chemical signalling | | | |  |
|  |  | | | |  |
| **3.D.3 Signal transduction pathways link signal reception with cellular response** | | | | | |
| 3.D.3a | Signaling begins with the recognition of a chemical messenger, a ligand, by a receptor protein | | | |  |
| 3.D.3a1 | Different receptors recognize different chemical messengers, which can be peptides, small chemicals or proteins, in a specific one-to-one relationship | | | |  |
| 3.D.3a2 | A receptor protein recognizes signal molecules, causing the receptor protein's shape to change, which initiates transduction of the signal.  *Example:*  *G-protein linked receptors*  *Ligand-gated ion channels*  *Receptor tyrosine kinases* | | | |  |
| 3.D.3b | Signal transduction is the process by which a signal is converted to a cellular response | | | |  |
| 3.D.3b1 | Signaling cascades relay signals from receptors to cell targets, often amplifying the incoming signals, with the result of appropriate responses by the cell | | | |  |
| 3.D.3b2 | Second messengers are often essential to the function of the cascade  *Examples:*  *Ligand-gated ion channels*  *Second messengers, such as cyclic GMP, cyclic AMP, calcium ions, and inositol triphosphosphate (IP3)* | | | |  |
| 3.D.3b3 | Many signal transduction pathways include  i. Protein modifications (an illustrative example could be how methylation changes the signalling process)  ii. Phosphorylation cascades in which a series of protein kinases add a phosphate group to the next protein in the cascade sequence | | | |  |
| LO3.36 | The student is able to describe a model that expresses the key elements of signal transduction pathways by which a signal is converted into a cellular response | | | |  |
|  |  | | | |  |
| **3.D.4 Changes in signal transduction pathways can alter cellular response** | | | | | |
| 3.D.4a | Conditions where signal transduction is blocked or defective can be deleterious, preventative, or prophylactic  *Examples:*  *Diabetes, heart disease, neurological disease, autoimmune disease, cancer, cholera*  *Effects of neurotoxins, poisons, pesticides*  *Drugs (hypertensives, anesthetics, antihistimines, and birth control drugs)*  *Exclusion: Specific mechanisms of these diseases and action of drugs* | | | | E.4.3 Explain how psychoactive drugs affect the brain and personality by either increasing or decreasing postsynaptic transmission  E.4.5 Explain the effects of THC and cocaine in terms of their action at synapses in the brain  E.4.6 Discuss the causes of addiction, including genetic predisposition, social factors, and dopamine secretion. |
| LO3.37 | The student is able to justify claims based on scientific evidence that changes in signal transduction pathways can alter cellular response | | | |  |
| LO3.38 | The student is able to describe a model that expresses key elements to show how change in signal transduction can alter cellular response | | | |  |
| LO3.39 | The student is able to construct an explanation of how certain drugs affect signal reception and, consequently, signal transduction pathways | | | |  |
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| **3.E.1 Individuals can act on information and communicate it to others** | | | | | |
| 3.E.1a | Organisms exchange information with each other in response to internal changes and external cues, which can change behavior.  *Examples:*  *Fight or flight response, predator warnings, protection of young, plant-plant interactions due to herbivory, avoidance responses* | | | | E.1.1 Define the terms *stimulus, response* and *reflex* in the context of animal behaviour. |
| 3.E.1b | Communication occurs through various mechanisms | | | |  |
| 3.E.1b1 | Living systems have a variety of signal behaviors or cues that produce changes in the behavior of other organisms and can result in differential reproductive success. *Examples: Herbivory responses, territorial marking in mammals, coloration in flowers* | | | | E.1.4 Explain how animal responses can be affected by natural selection, using two examples. |
| 3.E.1b2 | Animals use visual, audible, tactile, electrical and chemical signals to indicate dominance, find food, establish territory and ensure reproductive success. *Example: bee dances, bird songs, territorial marking in mammals, pack behavior in animals, herd, flock and schooling behavior in animals, predator warning, colony and swarming behavior in insects, coloration* | | | | E.2.1 Outline the diversity of stimuli that can be detected by human sensory receptors, including mechanoreceptors, chemoreceptors, thermoreceptors and photoreceptors. |
| 3.E.1c | Responses to information and communication of information are vital to natural selection and evolution | | | |  |
| 3.E.1c1 | Natural selection favors innate and learned behaviors that increase survival and reproductive fitness  *Examples: Parent and offspring interactions, migration patterns, courtship and mating behaviors, foraging in bees and other animals, avoidance behavior to electric fences, poisons, or traps* | | | | E.3.3 Analyse data from invertebrate behaviour experiments in terms of the effect on chances of survival and reproduction  E.3.4 Discuss how the process of learning can increase chances of survival  E.6.4 Outline two examples of how foraging behaviour optimizes food intake, including bluegill fish foraging for *Daphnia* |
| 3.E.1c2 | Cooperative behavior tends to increase the fitness of the individual and the survival of the population *Examples: Pack behavior in animals, herd, flock, and schooling behavior in animals, predator warning, colony and swarming behavior in insects. Exclusion: The details of the various communications and community behavioral systems.* | | | | E.6.1 Describe the social organization of honeybee colonies and one other non-human example  E.6.2 Outline how natural selection may act at the level of the colony in the case of social organisms.  E.6.3 Discuss the evolution of altruistic behaviour using two non-human examples. |
| LO3.40 | The student is able to analyze data that indicate how organisms exchange information in response to internal changes and external cues, and which can change behavior | | | |  |
| LO3.41 | The student is able to create a representation that describes how organisms exchange information in response to internal canges and external cues, and which can result in changes in behavior | | | |  |
| LO3.42 | The student is able to describe how organisms exchange information in response to internal changes or environmental cues | | | |  |
|  |  | | | |  |
| **3.E.2 Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses** | | | | | |
| 3.E.2a | The neuron is the basic structure of the nervous system that reflects function | | | | 6.5.1 State that the nervous system consists of the central nervous system (CNS) and peripheral nerves, and is composed of cells called neurons that can carry rapid electrical impulses. |
| 3.E.2a1 | A typical neuron has a cell body, axon, and dendrites. Many axons have a myelin sheath that acts as an electrical insulator. | | | | 6.5.2 Draw and label a diagram of a motor neuron. IB says: *Include dendrites, cell body with nucleus, axon, myelin sheath, nodes of Ranvier and motor end plates* |
| 3.E.2a2 | The structure of the neuron allows for the detection, generation, transmission, and integration of signal information. | | | | 6.5.3 State that nerve impulses are conducted from receptors to the CNS by sensory neurons, within the CNS by relay neurons, and from the CNS effectors by motor neurons |
| 3.E.2a3 | Schwann cells, which form the myelin sheath, are separated by gaps of unsheathed axon over which the impulse travels as the signal propagates along the neuron. | | | |  |
| 3.E.2b | Action potentials propagate impulses along neurons | | | | 6.5.5 Explain how a nerve impulse passes along a non-myelinated neuron |
| 3.E.2b1 | Membranes of neurons are polarized by the establishment of electrical potentials across membranes | | | | 6.5.4 Define *resting potential* and *action potential* (depolarization and repolarization) |
| 3.E.2b2 | In response to a stimulus, Na+ and K+ gated channels sequentially open and cause the membrane to become locally depolarized. | | | |  |
| 3.E.3b3 | Na+/K+ pumps, powered by ATP, work to maintain membrane potential | | | |  |
| 3.E.3c | Transmission of information between neurons occurs across synapses | | | |  |
| 3.E.3c1 | In most animals, transmission across synapses involve chemical messengers called neurotransmitters. *Examples: acetylcholine, epinephrine, norepinephrine, dopamine, serotonin, GABA* | | | | 6.5.6 Explain the principles of synaptic transmission. |
| 3.E.3c2 | Transmission of information along neurons and synapses results in a response | | | |  |
| 3.E.3c3 | The response can be stimulatory or inhibitory | | | | E.4.1 State that some presynaptic neurons excite postsynaptic transmission and others inhibit postsynaptic transmission  E.4.2 Explain how decision making in the CNS can result from the interaction between the activities of the excitatory and inhibitory presynaptic neurons at synapses  E.4.3 Explain how psychoactive drugs affect the brain and personality by either increasing or decreasing postsynaptic transmission |
| 3.E.3d | Different regions of the vertebrate brain have different functions. *Example: Vision, hearing, muscle movement, abstract thought and emotions, neurohormone production, forebrain (cerebrum), midbrain (brainstem), and hindbrain (cerebellum), right and left cerebral hemispheres in humans.* | | | | E.5.3 Explain how animal experiments, lesions, and FMRI (functional magnetic resonance imaging) scanning can be used in the identification of the brain part involved in specific functions. |
|  | *Exclusion: The types of nervous systems, development of the human nervous system, details of the various structures and features of the brain parts, and details of specific neurologic processes* | | | |  |
| LO3.43 | The student is able to construct an explanation, based on scientific theories and models, about how nervous systems detect external and internal signals, transmit and integrate information, and produce responses. | | | | E.5.4 Explain sympathetic and parasympathetic control of the heartrate, movements of the iris, and flow of blood to the gut. |
| LO3.44 | The student is able to describe how nervous systems detect external and internal signals | | | |  |
| LO3.45 | The student is able to describe how nervous systems transmit information | | | | E.1.2 Explain the role of receptors, sensory neurons, relay neurons, motor neurons, synapses, and effectors in the response of animals to stimuli.  E.1.3 Draw and label a diagram of a reflex arc for a pain withdrawal reflex, including the spinal cord and its spinal nerves, the receptor cell, sensory neuron, relay neuron, motor neuron and effector. |
| LO3.46 | The student is able to describe how the vertebrate brain integrates information to produce a response | | | | E.5.2 Outline the functions of each part of the brain listed in E.5.1 |
| LO3.47 | The student is able to create a visual representation of complex nervous systems to describe/explain how these systems detect external and internal signals, transmit and integrate information, and produce responses | | | |  |
| LO3.48 | The student is able to create a visual representation to describe how nervous systems detect external and internal signals | | | |  |
| LO3.49 | The student is able to create a visual representation to describe how nervous systems transmit information | | | |  |
| LO3.50 | The student is able to create a visual representation to describe how the vertebrate brain integrates information to produce a response | | | | E.5.1 Label, on a diagram of the brain, the medulla oblongata, cerebellum, hypothalamus, pituitary gland, and cerebral hemispheres. |
|  |  | | | |  |
| **4.A.1 The subcomponents of biological molecules and their sequence determine the properties of that molecules** | | | | | |
| 4.A.1a | Structure and function of polymers are derived from the way their monomers are assembled | | | |  |
| 4.A.1a1 | In nucleic acids, biological information is encoded in sequences of nucleotide monomers. Each nucleotide has structural components: a five-carbon sugar (deoxyribose or ribose), a phosphate and a nitrogen base (adenine, thymine, guanine, cytosine, or uracil). DNA and RNA differ in function and differ slightly in structure, and these structural differences account for the differing functions. | | | | 3.3, 3.5.1, 7.1 |
|  | *Exclusion: The molecular structure of specific nucleotides* | | | |  |
| 4.A.1a2 | In proteins, the specific order of amino acids in a polypeptide (primary structure) interacts with the environment to determine the overall shape of the protein, which also involves secondary, tertiary, and quaternary structure and, thus, its function. The R group of an amino acid can be categorized by chemical properties (hydrophobic, hydrophilic, and ionic) and the interactions of these R groups determine structure and function of that region of the protein. | | | | 7.5.1 Explain the four levels of protein structure, indicating the significance of each one.  7.5.2 Outline the difference between fibrous and globular proteins, with reference to two examples of each protein type.  7.5.3 Explain the significance of polar and nonpolar amino acids  7.5.4 State four functions of proteins, giving a named example of each. |
|  | *Exclusion: The molecular structure of specific amino acids* | | | |  |
| 4.A.1a3 | In general, lipids are nonpolar; however, phospholipids exhibit structural properties, with polar regions that interact with other polar molecules such as water, and with nonpolar regions where differences in saturation determine the structure and function of lipids. | | | | 3.2.6 State three functions of lipids IB says: *Include energy storage and thermal insulation.* |
|  | *Exclusion: The molecular structure of specific lipids* | | | |  |
| 4.A.1a4 | Carbohydrates are composed of sugar monomers who structures and bonding with each other by dehydration synthesis determine the properties and functions of the molecules. *Examples: Cellulose vs starch* | | | | 3.2.5 Outline the role of condensation and hydrolysis in the relationships between monosaccharides, disaccharides and polysaccharides; between fatty acids, glycerol and triglycerides; and between amino acids and polypeptides. |
|  | *Exclusion: The molecular structure of specific carbohydrates* | | | |  |
| 4.A.1b | Directionality influences structure and function of the polymer | | | |  |
| 4.A.1b1 | Nucleic acids have ends, defined by the 3' and 5' carbons of the sugar in the nucleotide, that determine the direction in which complementary nucleotides are added during DNA synthesis and the direction in which transcription occurs (from 5' to 3') | | | | 7.1.1, 7.2.1, 7.3.1, 7.4.4 |
| 4.A.1b2 | Proteins have an amino (NH2) end and a carboxyl (COOH) end, and consist of a linear sequence of amino acids connected by the formation of peptide bonds by dehydration synthesis between the amino and carboxyl groups of adjacent monomers | | | | 7.4.5 Draw and label a diagram showing the structure of a peptide bond between two amino acids.  3.2.5 |
| 4.A.1b3 | The nature of bonding between carbohydrate subunits determines their relative orientation in the carbohydrate, which then determines the secondary structure of the carbohydrate. | | | |  |
| LO4.1 | The student is able to explain the connection between the sequence and the subcomponents of a biological polymer and its properties | | | | 3.2.2 Identify amino acids, glucose, ribose and fatty acids from diagrams showing their structure |
| LO4.2 | The student is able to refine representations and models to explain how the subcomponents of a biological polymer and their sequence determine the properties of that polymer | | | | 3.2.5 Outline the role of condensation and hydrolysis in the relationships between monosaccharides, disaccharides and polysaccharides; between fatty acids, glycerol and triglycerides; and between amino acids and polypeptides. |
| LO4.3 | The student is able to use models to predict and justify that changes in the subcomponents of a biological polymer affect the functionality of the molecule | | | |  |
|  |  | | | |  |
| **4.A.2 The structure and function of subcellular components, and their interactions, provide essential cellular processes** | | | | | |
| 4.A.2a | Ribosomes are small, universal structures comprised of two interacting parts: ribosomal RNA and protein. In a sequential manner, these cellular components interact to become the site of protein synthesis where the translation of the genetic instructions yields specific polypeptides. | | | | 7.4.2 Outline the structure of ribosomes, including protein and RNA composition, large and small subunits, three tRNA binding sites and mRNA binding sites.  7.4.6 State that free ribosomes synthesize proteins for use primarily within the cell, and that bound ribosomes synthesize proteins primarily for secretion or for lysosomes. |
| 4.A.2b | Endoplasmic reticulum (ER) occurs in two forms: rough and smooth. | | | |  |
| 4.A.2b1 | Rough ER functions to compartmentalize the cell, serves as mechanical support, provides site-specific protein synthesis with membrane-bound ribosomes and plays a role in intracellular transport | | | | 2.3.2, 2.4.7 |
| 4.A.2b2 | In most cases, smooth ER synthesizes lipids  *Exclusion: Specific functions of smooth ER in specialized cells* | | | |  |
| 4.A.2c | The Golgi complex is a membrane-bound structure that consists of a series of flatterned membrane sacs (cisternae) | | | | 2.3.2, 2.4.7 |
| 4.A.2c1 | Functions of the Golgi include synthesis and packaging of materials (small molecules) for transport (in vesicles), and production of lysosomes. *Exclusion: The role of this organelle in specific phospholipid synthesis and the packaging of enzymatic contents of lysosomes, peroxisomes, and secretory vesicles.* | | | | 2.4.7 |
| 4.A.2d | Mitochondria specialize in energy capture and transformation | | | |  |
| 4.A.2d1 | Mitochondria have a double membrane that allow compartmentalization within the mitochondria and is important to its function | | | | 8.1.3 Draw and label a diagram showing the structure of a mitochondrion as seen in electron micrographs.  8.1.6 Explain the relationship between the structure of mitochondria and its function |
| 4.A.2d2 | The outer membrane is smooth, but the inner membrane is highly convoluted forming folds called cristae. | | | | 8.1.3, 8.1.6 |
| 4.A.2d3 | Cristae contain enzymes important to ATP production; cristae also increase the surface area for ATP production. | | | | 8.1.3, 8.1.6 |
| 4.A.2e | Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes, which are important in intracellular digestion, the recycling of a cell's organic materials and programmed cell death (apoptosis). Lysosomes carry out intracellular digestion in a variety of ways. *Exclusion: Specific examples of how lysosomes carry out intracellular digestion.* | | | | 2.3.2 |
| 4.A.2f | A vacuole is a membrane-bound sac that plays roles in intracellular digestion and the release of cellular waste products. In plants, a large vacuole serves many functions, from storage of pigments or poisonous substances to a role in cell growth. In addition, a large central vacuole allows for a large surface area to volume ratio. | | | | 2.3.5  2.3.7 |
| 4.A.2g | Chloroplasts are specialized organelles found in algae and higher plants that capture energy through photosynthesis. | | | | 2.3.5 State three differences between plant and animal cells |
| 4.A.2g1 | The structure and function relationship in chloroplasts allows cells to capture the energy available in sunlight and convert it to chemical bond energy via photosynthesis. | | | | 8.2.6 Explain the relationship between the structure of the chloroplast and its function  IB says: *Limit this to the large surface area of the thylakoids for light absorption, the small space inside thylakoids for accumulation of protons, and the fluid stroma for the enzymes of the Calvin cycle.* |
| 4.A.2g2 | Chloroplasts contain chlorophylls, which are responsible for the green color of a plant and are the key light-trapping molecules in photosynthesis. There are several types of chlorophyll, but the predominant form in plants is chlorophyll a. *Exclusion: The molecular structure of chlorophyll.* | | | | 3.8.3 State that chlorophyll is the main photosynthetic pigment.  3.8.4 Outline the differences in absorption of red, blue, and green light by chlorophyll. |
| 4.A.2g3 | Chloroplasts have a double outer membrane that creates a compartmentalized structure, which supports its function. Within the chloroplasts are membrane-bound structures called thylakoids. Energy-capturing reactions housed in the thylakoids are organized in stacks, called "grana", to produce ATP and NADPH2, which fuel carbon-fixing reactions in the Calvin-Benson cycle. Carbon fixation occurs in the stroma, where molecules of CO2 are converted into carbohydrates. | | | | 8.2.1 Draw and label a diagram showing the structure of a chloroplast as seen in electron micrographs. |
| LO4.4 | The student is able to make a prediction about the interactions of subcellular organelles. | | | |  |
| LO4.5 | The student is able to construct explanations based on scientific evidence as to how interactions of subcellular structures provide essential functions. | | | |  |
| LO4.6 | The student is able to use representations and models to analyze situations qualitatively to describe how interactions of subcellular structures, which possess specialized functions, provide essential functions. | | | |  |
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| **4.A.3 Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs** | | | | | |
| 4.A.3a | Differentiation in development is due to external and internal cues that trigger gene regulation by proteins that bind to DNA | | | |  |
| 4.A.3b | Structural and functional divergence of cells in development is due to expression of genes specific to a particular tissue or organ type | | | | 2.1.8 Explain that cells in multicellular organisms differentiate to carry out specialized functions by expressing some of their genes but not others |
| 4.A.3c | Environmental stimuli can affect gene expression in a mature cell | | | |  |
| LO 4.7 | The student is able to refine representations to illustrate how interactions between external stimuli and gene expression result in specialization of cells, tissues and organs | | | |  |
|  |  | | | |  |
| **4.A.4 Organisms exhibit complex properties due to interactions between their constituent parts** | | | | | |
| 4.A.4a | Interactions and coordination between organs provide essential biological activities. *Examples: Stomach and small intestine; kidney and bladder; root, stem and leaf* | | | | 6.1.5 Outline the function of the stomach, small intestine, and large intestine. |
| 4.A.4b | Interactions and coordination between systems provide essential biological activities. *Examples: Respiratory and circulatory, nervous and muscular, plant vascular and leaf.* | | | |  |
| LO4.8 | The student is able to evaluate scientific questions concerning organisms that exhibit complex properties due to the interaction of their constituent parts. | | | |  |
| LO4.9 | The student is able to predict the effects of a change in a component of a biological system on the functionality of the organism | | | |  |
| LO4.10 | The student is able to refine representations and models to illustrate biocomplexity due to interactions of the constituent parts | | | |  |
|  |  | | | |  |
| **4.A.5 Communities are composed of populations of organisms that interact in complex ways** | | | | | |
| 4.A.5a | The structure of a community is measured and described in terms of species composition and species diversity | | | |  |
| 4.A.5b | Mathematical or computer models are used to illustrate and investigate population interactions within and environmental impacts on a community. *Examples: Predator/prey spreadsheet model, symbiotic relationship, graphical representation of field data, introduction of species, global climate change models* | | | | 5.3 |
| 4.A.5c | Mathematical models and graphical representations are used to illustrate population growth patterns and interactions | | | | 5.3 |
| 4.A.5c1 | Reproduction without constraints results in the exponential growth of a population | | | | 5.3 |
| 4.A.5c2 | A population can produce a density of individuals that exceeds the system's resource availability | | | |  |
| 4.A.5c3 | As limits to growth due to density-dependent and density-independent factors are imposed, a logistic growth model generally ensues | | | |  |
| 4.A.5c4 | Demographics data with respect to age distributions and fecundity can be used to study human populations. | | | |  |
| LO 4.11 | The student is able to justify the selection of the kind of data needed to answer scientific questions about the interaction of populations within communities | | | |  |
| LO 4.12 | The student is able to apply mathematical routines to quantities that describe communities composed of populations of organisms that interact in complex ways | | | |  |
| LO 4.13 | The student is able to predict the effects of a change in the community's populations on the community | | | |  |
|  |  | | | |  |
| **4.A.6 Interactions among living systems and with their environment result in the movement of energy and matter** | | | | | |
| 4.A.6a | Energy flows but matter is recycled | | | | 5.1.13 Explain that energy enters and leaves ecosystems but nutrients must be recycled.  5.1.14 State that saprotrophic bacteria and fungi (decomposers) recycle nutrients.  5.2.1 Draw and label a diagram of the carbon cycle to show the processes involved  IB says: *The details of the carbon cycle should include the interaction of living organisms and the biosphere through the processes of photosynthesis, cell respiration, fossilization and combustion. Recall of specific quantitative data is not required.* |
| 4.A.6b | Changes in regional and global climates and in atmospheric composition influence patterns of primary productivity | | | | 5.2.6 Outline the consequences of a global temperature rise on arctic ecosystems. |
| 4.A.6c | Organisms within food chains and food webs interact | | | | 5.1.3 Distinguish between *consumers*, *detritovores*, and *saprotrophs*  5.1.4 Describe what is meant by a food chain, giving three examples, each with at least three linkages (four organisms)  5.1.5 Describe what is meant by a food web  5.1.8 Construct a food web containing up to 10 organisms, using appropriate information |
| 4.A.6d | Food webs and food chains are dependent on primary productivity | | | |  |
| 4.A.6e | Models allow the prediction of the impact of change in biotic and abiotic factors | | | |  |
| 4.A.6e1 | Competition for resources and other factors limits growth and can be described by the logistic model | | | |  |
| 4.A.6e2 | Competition for resources, territoriality, health, predation, accumulation of wastes and other factors contribute to density-dependent population regulation. | | | |  |
| 4.A.6f | Human activities impact ecosystems on local, regional, and global scales. | | | |  |
| 4.A.6f1 | As human populations have increased in numbers, their impact on habitats for other species have been magnified | | | |  |
| 4.A.6f2 | In turn, this has often reduced the population size of the affected species and resulted in habitat destruction and, in some cases, extinction of species | | | |  |
| 4.A.6g | Many adaptations of organisms are related to obtaining and using energy and matter in a particular environment | | | |  |
| LO 4.14 | The student is able to apply mathematical routines to quantities that describe interactions among living systems and their environment, which result in the movement of matter and energy. | | | |  |
| LO 4.15 | THe student is able to use visual representations to analyze situations or solve problems qualitatively to illustrate how interactions among living systems and with their environment result in the movement of energy and matter | | | |  |
| LO 4.16 | The student is able to predict the effects of a change of matter or energy availability on communities | | | |  |
|  |  | | | |  |
| **4.B.1 Interactions between molecules affect their structure and function** | | | | | |
| 4.B.1a | Change in the structure of a molecular system may result in the change of the function of the system | | | |  |
| 4.B.1b | The shape of enzymes, active sites and interaction with specific molecules are essential for the basic functioning of an enzyme | | | | 3.6.1 Define *enzyme* and *active site*  6.1.2 Explain the need for enzymes in digestion. |
| 4.B.1b1 | For an enzyme-mediated chemical reaction to occur, the substrate must be complementary to the surface properties (shape and charge) of the active site. In other words, the substrate must fit into the enzyme's active site. | | | | 3.6.2 Explain enzyme-substrate specificity  3.6.4 Define *denaturation*  7.6.2 Describe the induced-fit model  7.6.3 Explain that enzymes lower the activation energy of the chemical reactions that they catalyse |
| 4.B.1b2 | Cofactors and coenzymes affect enzyme function; this interaction relates to a structural change that alters the activity rate of the enzyme. The enzyme may only become active when all the appropriate cofactors or coenzymes are present and bind to the appropriate sites on the enzyme | | | |  |
|  | *Exclusion: No specific cofactors or coenzymes* | | | |  |
| 4.B.1c | Other molecules and the environment in which the enzyme acts can enhance or inhibit enzyme activity. Molecules can bind reversibly or irreversibly to the active or allosteric sites, changing the activity of the enzyme. | | | | 7.6.4 Explain the difference between competitive and non-competitive inhibition, with reference to one example of each  7.6.5 Explain the control of metabolic pathways by end-product inhibition including the role of allosteric sites. |
| 4.B.1d | The change in function of an enzyme can be interpreted from data regarding the concentrations of product or substrate as a function of time. These representations demonstrate the relationship between an enzyme's activity, the disappearance of substrate, and/or presence of a competitive inhibitor. | | | | 3.6.3 Explain the effects of temperature, pH, and substrate concentration on enzyme activity |
| LO4.17 | The student is able to analyze data to identify how molecular interactions affect structure and function. | | | |  |
|  |  | | | |  |
| **4.B.2 Cooperative interactions within organisms promote efficiency in the use of energy and matter** | | | | | |
| 4.B.2a | Organisms have areas or compartments that perform a subset of functions related to energy and matter, and these parts contribute to the whole | | | |  |
| 4.B.2a1 | At the cellular level, the plasma membrane, cytoplasm, and, for eukaryotes, the organelles contribute to the overall specialization and functioning of the cell | | | |  |
| 4.B.2a2 | Within multicellular organisms, specialization of organs contributes to the overall functioning of the organism  *Examples: exchange of gases, circulation of fluids, digestion of food, excretion of wastes* | | | |  |
| 4.B.2a3 | Interactions among cells of a population of unicellular organisms can be similar to those of multicellular organisms, and these interactions lead to increased efficiency and utilization of energy and matter. *Examples: Bacterial community in the rumen of animals; bacterial community in and around deep sea vents* | | | |  |
| LO4.18 | The student is able to use representations and models to analyze how cooperative interactions within organisms promote efficiency in the use of energy and matter | | | |  |
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| **4.B.3 Interactions between and within populations influence patterns of species distribution and abundance** | | | | | |
| 4.B.3a | Interactions between populations affect the distributions and abundance of populations | | | |  |
| 4.B.3a1 | Competition, parasitism, predation, mutualism, and commensalism can affect population dynamics | | | |  |
| 4.B.3a2 | Relationships among interacting populations can be characterized by positive and negative effects, and can be modeled mathematically (predator/prey, epidemiological models, invasive species) | | | |  |
| 4.B.3a3 | Many complex symbiotic relationships exist in an ecosystem, and feedback control systems play a role in the functioning of these ecosystems. *Exclusion: Specific symbiotic interactions* | | | |  |
| 4.B.3b | A population of organisms has properties that are different from those of the individuals that make up the population. The cooperation and competition between individuals contributes to these different properties. | | | |  |
| 4.B.3c | Species-specific and environmental catastrophes, geological events, the sudden influx/depletion of abiotic resources or increased human activities affect species distribution and abundance. *Examples: Loss of keystone species, kudzu, dutch elm disease* | | | |  |
| LO4.19 | The student is able to use data analysis to refine observations and measurements regarding the effect of population interactions on patterns of species distribution and abundance. | | | |  |
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| **4.B.4 Distribution of local and global ecosystems changes over time** | | | | | |
| 4.B.4a | Human impact accelerates change at local and global levels  *Examples:*  *Logging, slash and burn agriculture, urbanization, monocropping, infrastructure development (dams, transmission lines, roads), and global climate change threaten ecosystems and life on earth*  *An introduced species can exploit a new niche free of predators or competitors, thus exploiting new resources*  *Introduction of new diseases can devastate native species (dutch Elm disease, potato blight, smallpox)* | | | |  |
| 4.B.4b | Geological and meteorological events impact ecosystem distribution | | | |  |
| 4.B.4b1 | Biogeographical studies illustrate these changes *Examples: El nino, continental drift, meteor impact on dinosaurs* | | | |  |
| LO4.20 | The student is able to explain how the distribution of ecosystems changes over time by identifying large scale events that have resulted in these changes in the past | | | |  |
| LO4.21 | The student is able to predict consequences of human actions on both local and global ecosystems | | | | 5.2.2 Analyse the changes in concentration of atmospheric carbon dioxide using historical records  5.2.3 Explain the relationship between rises in concentrations of atmospheric carbon dioxide, methane, and oxides of nitrogen and the enhanced greenhouse effect  5.2.4 Outline the precautionary principle  5.2.5 Evaluate the precautionary principle as a justification for strong action in response to the threats posed by the enhanced greenhouse effect.  5.2.6 Outline the consequences of a global temperature rise on arctic ecosystems. |
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| **4.C.1 Variation in molecular units provides cells with a wider range of functions** | | | | | |
| 4.C.1a | Variations within molecular classes provides cells and organisms with a wider range of functions. *Examples: Different types of phospholipids in cell membranes; different types of hemoglobin; MHC proteins; chlorophylls; molecular diversity of antibodies in response to an antigen* | | | |  |
| 4.C.1b | Multiple copies of alleles of genes (gene duplication) may provide new phenotypes | | | | 4.3.4 Describe ABO blood groups as an example of codominance and multiple alleles |
| 4.C.1b1 | A heterozygote may be a more advantageous genotype than a homozygote under particular conditions, since with two different alleles, the organism has two forms of proteins that may provide functional resilience in response to environmental stresses | | | | D.2.11 Describe sickle-cell anemia as an example of balanced polymorphism. |
| 4.C.1b2 | Gene duplication creates a situation in which one copy of the gene maintains its original function, while the duplicate may evolve a new function. *Example: The antifreeze gene in fish* | | | |  |
| LO 4.22 | The student is able to construct explanations based on evidence of how variation in molecular units provides cells with a wider range of functions | | | |  |
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| **4.C.2 Environmental factors influence the expression of the genotype in an organism** | | | | | |
| 4.C.2a | Environmental factors influence many traits both directly and indirectly  *Examples: Height and weight in humans, flower color based on soil pH, seasonal fur color in arctic animals, sex determination in reptiles, density of plant hairs as a function of herbivory, effect of adding lactose to a Lac+ bacteria culture, effect of increased UV on melanin production in animals, presence of the opposite mating type on pheromones production in yeast and other fungi* | | | |  |
| 4.C.2b | A organism's adaption to the local environment reflects a flexible response of its genome. *Example: Darker fur in cooler regions of the body in certain mammals; alterations in timing of flowering due to climate changes* | | | |  |
| LO 4.23 | The student is able to construct explanations of the influence of environmental factors on the phenotype of an organism | | | |  |
| LO 4.24 | The student is able to predict the effects of a change in an environmental factor on the genotypic expression of the phenotype | | | |  |
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| **4.C.3 The level of variation in a population affects population dynamics** | | | | | |
| 4.C.3a | Population ability to respond to changes in the environment is affected by genetic diversity. Species and populations with little genetic diversity are at risk for extinction. *Examples: California condors, black-footed ferrets, prairie chickens, potato blight causing the potato famine, corn rust affects of agricultural crops, Tasmanian devils and infectious cancers* | | | |  |
| 4.C.3b | Genetic diversity allows individuals in a population to respond differently to the same changes in environmental conditions. *Example: Not all animals in a population stampede; not all indviduals in a population in a disease outbreak are equally affected: some may not show symptoms, some may have mild symptoms, or some may be naturally immune and resistant to the disease* | | | | 5.4.7 Explain how natural selection leads to evolution |
| 4.C.3c | Allelic variation within a population can be modeled by the Hardy-Weinberg equations | | | |  |
| LO 4.25 | The student is able to use evidence to justify a claim that a variety of phenotypic responses to a single environmental factor can result from different genotypes within the population | | | |  |
| LO 4.26 | The student is able to use theories and models to make scientific claims and/or predictions about the effects of variation within populations on survival and fitness. | | | |  |
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| **4.C.4 The diversity of species within an ecosystem may influence the stability of the ecosystem** | | | | | |
| 4.C.4a | Natural and artificial ecosystems with fewer component parts and with little diversity among the parts are often less resilient to changes in the environment | | | |  |
| 4.C.4b | Keystone species, producers, and essential abiotic and biotic factors contribute to maintaining the diversity of an ecosystem. The effects of keystone species on the ecosystem are disproportionate relative to their abundance in the ecosystem, and when they are removed from the ecosystem, the ecosystem often collapses. | | | |  |
| LO4.27 | The student is able to make scientific claims and predictions about how species diversity within an ecosystem influences ecosystem stability. | | | |  |

**Topics in IB *not* covered in AP**

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| 1.1.1 | State that error bars are a graphical representation of the variability of data. |
| 1.1.2 | Calculate the mean and standard deviation of a set of values |
| 1.1.3 | State that the term standard deviation is used to summarize the spread of values around the mean, and that 68% of values within one standard deviation of the mean. |
| 1.1.4 | Explain how the standard deviation is useful for comparing the means and spread of data between two or more samples. |
| 1.1.5 | Deduce the significance of the difference between two sets of data using calculated values for t and the appropriate tables. |
| 1.1.6 | Explain that the existence of a correlation does not establish that there is a causal relationship between two variables. |

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| 2.1.1 | Outline the cell theory |
| 2.1.2 | Discuss the evidence for the cell theory |
| 2.1.3 | State that unicellular organisms carry out all the functions of life |
| 2.1.4 | Compare the relative sizes of molecules, cell membrane thickness, viruses, bacteria, organelles and cells, using the appropriate SI unit. |
| 2.1.5 | Calculate the linear magnification of drawings and the actual size of specimens in images of known magnification |
| 2.1.7 | State the multicellular organisms show emergent properties |
| 2.1.10 | Outline one therapeutic use of stem cells. |

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| 2.2.3 | Identify structures from 2.2.1 in electron micrographs of *E. coli* |
| 2.2.4 | State that prokaryotic cells divide by binary fission |

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| 2.3.3 | Identify structures from 2.3.1 in electron micrographs of liver cells. |

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| 3.1.2 | State that a variety of other elements are needed by living organisms, including sulfur, calcium, phosphorus, iron, and sodium |
| 3.1.3 | State one role for each of the elements mentioned in 3.1.2 |

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| 3.2.1 | Distinguish between *organic* and *inorganic* compounds |
| 3.2.3 | List three examples each of monosaccharides, disaccharides, and polysaccharides. |
| 3.2.4 | State one function of glucose, lactose, and glycogen in animals, and of fructose, sucrose, and cellulose in plants. |
| 3.6.5 | Explain the use of lactase in the production of lactose-free milk |

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| 3.8.2 | State that light from the Sun is composed of a range of wavelengths (colours). |
| 3.8.7 | Explain that the rate of photosynthesis can be measured directly by the production of oxygen or the uptake of carbon dioxide, or indirectly by an increase in biomass. |
| 4.2.5 | State that, in karyotyping, chromosomes are arranged in pairs according to their size and structure |
| 4.2.6 | State that karyotyping is performed using cells collected by chorionic villus sampling or amniocentesis, for pre-natal diagnosis of chromosome abnormalities. |
| 4.2.7 | Analyse a human karyotype to determine gender and whether non-disjunction has occurred |

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| 5.5.1 | Outline the binomial system of nomenclature |
| 5.5.2 | List seven levels in the hierarchy of taxa—kingdom, phylum, class, order, family, genus, and species—using an example from two different kingdoms for each level |
| 5.5.3 | Distinguish between the following phyla of plants, using simple external recognition features: *bryophyta, filicinophyta, coniferophyta,* and *angiospermaphyta* |
| 5.5.4 | Distinguish between the following phyla of animals, using simple external recognition features: *porifera*, *cnidaria*, *platyhelminthes,* *annelida, mollusca*, *arthropoda* |
| 5.5.5 | Apply and design a key for a group of up to eight organisms |

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| 6.1.1 | Explain why digestion of large food molecules is essential. |
| 6.1.3 | State the source, substrate, products, and optimum pH conditions for one amylase, one protease, and one lipase |
| 6.1.4 | Draw and label a diagram of the digestive system |
| 6.1.6 | Distinguish between absorption and assimilation |

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| 6.2.1 | Draw and label a diagram of the heart showing the four chambers, associated blood vessels, valves, and the route of blood through the heart. |
| 6.2.2 | State that the coronary arteries supply heart muscle with oxygen and nutrients. |
| 6.2.3 | Explain the action of the heart in terms of collecting blood, pumping blood, and opening and closing of valves. |
| 6.2.4 | Outline the control of the heartbeat in terms of myogenic muscle contraction, the role of the pacemaker, nerves, the medulla of the brain, and epinephrine (adrenaline) |
| 6.2.5 | Explain the relationship between the structure and function of arteries, capillaries, and veins. |
| 6.2.6 | State that blood is composed of plasma, erythrocytes, leucocytes (phagocytes and lymphocytes) and platelets |
| 6.2.7 | State that the following are transported by the blood: nutrients, oxygen, carbon dioxide, hormones, antibodies, urea, and heat |

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| 6.3.2 | Explain why antibiotics are effective against bacteria but not against viruses. |
| 6.3.7 | Outline the effects of HIV on the immune system |
| 6.3.8 | Discuss the cause, transmission, and social implications of AIDS. |

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| 6.4.1 | Distinguish between *ventilation, gas exchange,* and *cell respiration* |
| 6.4.2 | Explain the need for a ventilation system |
| 6.4.3 | Describe the features of alveoli that adapt them to gas exchange. |
| 6.4.4 | Draw and label a diagram of the ventilation system, including trachea, lungs, bronchi, bronchioles, and alveoli |
| 6.4.5 | Explain the mechanism of ventilation of the lungs in terms of volume and pressure changes caused by the internal and external intercostals muscles, the diaphragm, and abdominal muscles. |

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| 6.6.1 | Draw and label diagrams of the adult male and female reproductive systems |
| 6.6.2 | Outline the role of hormones in the menstrual cycle, including FSH (follicle stimulating hormone), LH (luteinizing hormone), estrogen and progesterone. |
| 6.6.3 | Annotate a graph showing the hormone levels in the menstrual cycle, illustrating the relationship between changes in hormone levels and ovulation, menstruation, and thickening of the endometrium. |
| 6.6.4 | List three roles of testosterone in males |
| 6.6.5 | Outline the process of *in vitro* fertilization (IVF) |
| 6.6.6 | Discuss the ethical issues associated with IVF |

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| 7.1.2 | Outline the structure of nucleosomes |
| 7.1.3 | State that nucleosomes help to supercoil chromosomes and help to regulate transcription. |
| 7.1.4 | Distinguish between *unique or single-copy genes* and *highly repetitive sequences* in nuclear DNA. |
| 7.3.2 | Distinguish between the *sense* and *antisense* strands of DNA |
| 7.4.1 | Explain that each tRNA molecule is recognized by a tRNA-activating enzyme that binds a specific amino acid to the tRNA, using ATP for energy. |

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| 8.1.1 | State that oxidation involves the loss of electrons from an element, whereas reduction involves a gain of electrons; and that oxidation frequently involves gaining oxygen or losing hydrogen, whereas reduction frequently involves losing oxygen or gaining hydrogen. |
| 8.2.7 | Explain the relationship between the action spectrum and the absorption spectrum of photosynthetic pigments in green plants |
| 8.2.8 | Explain the concept of limiting factors in photosynthesis, with reference to light intensity, temperature, and concentration of carbon dioxide. |

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| 9.1.1 | Draw and label plan diagrams to show the distribution of tissues in the stem and leaf of a dicotyledonous plant |
| 9.1.2 | Outline three differences between the structures of dicotyledonous and monocotyledonous plants. |
| 9.1.3 | Explain the relationship between the distribution of tissues in the leaf and the functions of these tissues. |
| 9.1.4 | Identify modifications of roots, stems and leaves for different functions: bulbs, stem tubers, storage roots and tendrils. |
| 9.1.5 | State that dicotyledonous plants have apical and lateral meristems. |
| 9.1.6 | Compare growth due to apical and lateral meristems in dicotyledonous plants. |
| 9.2.1 | Outline how the root system provides a large surface area for mineral ion and water uptake by means of branching and root hairs. |
| 9.2.2 | List ways in which mineral ions in the soil move to the root. |
| 9.2.3 | Explain the process of mineral ion absorption from the soil into roots by active transport. |
| 9.2.4 | State that terrestrial plants support themselves by means of thickened cellulose, cell turgor, and lignified xylem. |
| 9.2.5 | Define *transpiration* |
| 9.2.6 | Explain how water is carried by the transpiration stream, including the structure of xylem vessels, transpiration pull, cohesion, adhesion and evaporation. |
| 9.2.11 | Outline the role of phloem in active translocation of sugars (sucrose) and amino acids from source (photosynthetic tissue and storage organs) to sink (fruit, seeds, roots). |
| 9.3.1 | Draw and label a diagram showing the structure of a dicotyledonous animal-pollinated flower. |
| 9.3.2 | Distinguish between *pollination*, *fertilization,* and *seed dispersal*. |
| 9.3.3 | Draw and label a diagram showing the external and internal structure of a named dicotyledonous seed. |

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| * 10.3.1 | * Define *polygenic inheritance* |
| * 10.3.2 | * Explain that polygenic inheritance can contribute to continuous variation using two examples, one of which must be human skin color |

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| 11.1.5 | Describe the production of monoclonal antibodies and their use in diagnosis and in treatment. |
| 11.1.7 | Discuss the benefits and dangers of vaccination. |
| 11.2.1 | State the roles of bones, ligaments, muscles, tendons and nerves in human movement. |
| 11.2.2 | Label a diagram of the human elbow joint, including cartilage, synovial fluid, joint capsule, named bones and antagonistic muscles (biceps and triceps). |
| 11.2.3 | Outline the functions of the structures in the human elbow joint named in 11.2.2 |
| 11.2.4 | Compare the movements of the hip joint and the knee joint. |
| 11.2.5 | Describe the structure of striated muscle fibres, including the myofibrils with light and dark bands, mitochondria, the sarcoplasmic reticulum, nuclei, and the sarcolemma. |
| 11.2.6 | Draw and label a diagram to show the structure of a sarcomere, including Z lines, actin filaments, myosin filaments with heads, and the resultant light and dark bands. |
| 11.2.7 | Explain how skeletal muscle contracts, including the release of calcium ions from the sarcoplasmic reticulum, the formation of cross-bridges, the sliding of actin and myosin filaments, and the use of ATP to break cross-bridges and re-set myosin heads. |
| 11.2.8 | Analyse electron micrographs to find the state of contraction of muscle fibres. |
| 11.3.1 | Define *excretion* |
| 11.3.2 | Draw and label a diagram of the kidney. |
| 11.3.3 | Annotate a diagram of a glomerulus and associated nephron to show the function of each part. |
| 11.3.4 | Explain the process of ultrafiltration, including blood pressure, fenestrated blood capillaries, and basement membrane. |
| 11.3.5 | Define *osmoregulation.* |
| 11.3.6 | Explain the reabsorption of glucose, water, and salts in the proximal convoluted tubule, including the roles of microvilli, osmosis and active tranport. |
| 11.3.7 | Explain the roles of the loop of Henle, medulla, collecting duct and ADH (vasopressin) in maintaining the water balance of the blood. |
| 11.3.8 | Explain the differences in the concentration of proteins, glucose and urea between blood plasma, glomerular filtrate and urine. |
| 11.3.9 | Explain the presence of glucose in the urine of untreated diabetic patients. |
| 11.4.1 | Annotate a light micrograph of testis tissue to show the location and function of interstitial cells (Leydig cells), germinal epithelium cells, developing spermatozoa and Sertoli cells. |
| 11.4.2 | Outline the processes involved in spermatogenesis within the testis, including mitosis, cell growth, the two divisions of meiosis and cell differentiation. |
| 11.4.3 | State the role of LH, testosterone and FSH in spermatogenesis. |
| 11.4.4 | Annotate a diagram of the ovary to show the location and function of germinal epithelium, primary follicles, mature follicle and secondary oocyte. |
| 11.4.5 | Outline the processes involved in oogenesis within the ovary, including mitosis, cell growth, the two divisions of meiosis, the unequal division of cytoplasm and the degeneration of polar body. |
| 11.4.6 | Draw and label a diagram of a mature sperm and egg. |
| 11.4.7 | Outline the role of the epididymis, seminal vesicle and prostate gland in the production of semen. |
| 11.4.8 | Compare the processes of spermatogenesis and oogenesis, including the number of gametes and the timing of the formation and release of gametes. |
| 11.4.9 | Describe the process of fertilization, including the acrosome reaction, penetrating of the egg membrane by a sperm and the cortical reaction |
| 11.4.10 | Outline the role of HCG in early pregnancy. |
| 11.4.11 | Outline early embryo development up to the implantation of the blastocyst. |
| 11.4.12 | Explain how the structure and functions of the placenta, including its hormonal role in secretion of estrogen and progesterone, maintain pregnancy. |
| 11.4.13 | State that the fetus is supported and protected by the amniotic sac and amniotic fluid. |
| 11.4.14 | State that materials are exchanged between the maternal and fetal blood in the placenta. |

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| D.1.6 | State that living cells may have been preceded by protobionts, with an internal chemical environment different from their surroundings. |
| D.1.8 | Discuss the endosymbiotic theory for the origin of eukaryotes. |

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| D.2.8 | Compare convergent and divergent evolution |
| D.2.9 | Discuss ideas on the pace of evolution, including gradualism and punctuated equilibrium. |
| D.2.10 | Describe one example of transient polymorphism. |

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| D.3.4 | Describe the major anatomical features that define humans as primates. |
| D.3.5 | Outline the trends illustrated by the fossils of *Ardipithecus ramidus*, *Australopithecus* including *A. afarensis* and *A. africanus*, and *Homo* including *H. habilius, H. erectus, H. neanderthalensis* and *H. sapiens.* |
| D.3.6 | State that, at various stages in hominid evolution, several species may have coexisted. |

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| D.3.8 | Discuss the correlation between the change in diet and increase in brain size during hominid evolution. |
| D.3.9 | Distinguish between *genetic* and *cultural* evolution. |
| D.3.10 | Discuss the relative importance of genetic and cultural evolution in the recent evolution of humans. |

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| D.5.1 | Outline the value of classifying organisms |

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| E.2.2 | Label a diagram of the structure of the human eye. |
| E.2.3 | Annotate a diagram of the retina to show the cell types and the direction in which light moves. |
| E.2.4 | Compare rod and cone cells |
| E.2.5 | Explain the processing of visual stimuli, including edge enhancement and contralateral processing. |
| E.2.6 | Label a diagram of the ear. |
| E.2.7 | Explain how sound is perceived by the ear, including the roles of the eardrum, bones of the middle ear, oval and round windows, and the hair cells of the cochlea. |

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| E.4.4 | List three examples of excitatory and three examples of inhibitory psychoactive drugs. |
| E.4.5 | Explain the effects of THC and cocaine in terms of their action at synapses in the brain |
| E.4.6 | Discuss the causes of addiction, including genetic predisposition, social factors, and dopamine secretion. |
| E.5.5 | Explain the pupil reflex |
| E.5.6 | Discuss the concept of brain death and the use of the pupil reflex in testing for this |
| E.5.7 | Outline how pain is perceived and how endorphins can act as painkillers |